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A GEOGRAPHIC INFORMATION SYSTEM ASSESSMENT METHOD FOR  
FIRE MANAGEMENT: IDENTIFYING FIRE DANGER AREAS

by

Richard D. Stratton

A thesis submitted in partial fulfillment  
of the requirements for the degree

of

MASTER OF SCIENCE

in

Forestry

UTAH STATE UNIVERSITY  
Logan, Utah

1998

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## ABSTRACT

### A Geographic Information System Assessment Method for Fire Management: Identifying Fire Danger Areas

by

Richard D. Stratton, Master of Science

Utah State University, 1998

Major Professor: Dr. Michael J. Jenkins  
Department: Forest Resources

In partnership with the USDA Forest Service and the Utah Division of Forestry, Fire, and State Lands, a geographic information system (GIS) was used to create a wildland fire assessment methodology. GIS layers (or themes) include topography, infrastructure, vegetation, climate, "sensitive" natural values, and fire history. Two phases of assessment are presented: a preliminary analysis designed for planning use at the landscape level, and a detailed analysis for site-specific use.

Results of the phase 1 assessment are density grids delineating areas of high fire occurrence and suggesting to managers where a phase 2 assessment is needed. By using the environmental, human, and topographic information listed earlier, probability maps of wildland fire occurrence were developed with a



GIS and multiple logistic regression. In both cases, high fire danger areas can be overlaid with protection areas (natural or human-made value areas) to identify critical fire danger areas.

Because GIS is commonly used in land management, it facilitates the sharing and updating of geographic information between resource professionals of different agencies and organizations. Local officials will be able to use GIS spatial and tabular data for planning, zoning, and fire ordinance development. Land management specialists can locate, prioritize, and target high and critical fire danger areas for presuppression mitigation efforts such as prescribed fires, defensible-space projects, and fire-break construction (e.g., greenbelts, parkways).

Furthermore, GIS assessment layers can be manipulated and exported to create the required raster GIS data themes for FARSITE (a fire growth simulator). Fire managers will be able to spatially predict fire spread, intensity, and behavior under complex topographic and climatic conditions. This method, combined with the expertise of fire specialists, offers an improved and cost-effective assessment technique for wildland fire management.

(115 pages)

To laugh often and much;  
To win the respect of  
Intelligent persons and the  
Affection of children;  
To earn the appreciation of  
Honest critics and endure the  
Betrayal of false friends;  
To appreciate beauty;  
To find the best in others;  
To leave the world a bit better,  
Whether by a healthy child,  
A garden patch,  
Or a redeemed social condition;  
To know even one life has breathed  
Easier because you have lived.  
This is to have succeeded.

Ralph Waldo Emerson

## ACKNOWLEDGMENTS

The completion of this thesis depended on an inordinate amount of support from a variety of professionals and organizations. I thank the members of my thesis committee, Dr. Michael Jenkins, Dr. David Winn, Dr. Michael Kuhns, and John Ellsworth MLA, for their encouragement and thoughtful suggestions and critiques. Also, several other professors and technicians from the Geography and Forest Resources Departments aided me in completion of this thesis (Dr. Douglas Ramsey, Collin Homer, Bonnie Banner, Thad Tilton, Brad Wright, Kim Patraw, Tom Van Niel, Nathan Bentley, and Joel Godfrey). Of special note is Dr. Charles Romesburg. I admire him, have learned much from, and cherish his advice and friendship.

I express my gratitude to the USDA Forest Service, particularly the Intermountain Region (Region 4), the Logan Ranger District, Rocky Mountain Research Station (Logan), and the supervisor's office of the Wasatch-Cache National Forest.

The regional office provided critical technical support and funding for this project from a variety of staffs, namely, GIS and remote sensing, fire management, cartography and graphics, and the Rocky Mountain Research Station Library. Many thanks to Dave Prevedel, Dave George, Jim Shell, Jeannette Hartog, Jeanne Felmy, Lucy Ewing, and Clair Beasley. A special, heartfelt "thank you" is extended to Teresa Rhoades and Sue Johnson, also of

the regional office. Without their GIS expertise, patience, and good humor, I would not have been able to complete this project. I will always be thankful for them and will miss them.

To the folks at the Logan Ranger District--Jerry Brunner, John Balph, Connie McCaughey, Ann Judkins, L.J. Western, and Scott Bushman--thank you for "taking me in" and extending your trust and support.

Also, many professionals at the Rocky Mountain Research Station and the supervisor's office helped me. I am deeply indebted to Dr. David Turner, the statistical expert of this project. His knowledge of statistics is astounding; his contributions substantial. The strength and success of this project can largely be attributed to him. I sincerely appreciate his efforts as well as those of Michael Barry, Linda Wadleigh, Paul Flood, Mike Monahan, Dan Arling, and Wayne Padgett. Additional thanks is extended to the Utah Division of Forestry, Fire, and State Lands (Craig Pettigrew), Cache County (Kelly Pitcher, Jeff Peterson, and Mark Teuscher), and Rich County (Dan Ames).

Lastly, I thank my parents for teaching me the importance of faith, work, education, and honor. In great measure my past and future success and happiness I owe to their love and undeviating commitment. And of course, to my new bride, Shelly, thank you for being so positive, supportive, and unselfish at a delicate time in our lives. I look forward to our wonderful life ahead.

Rick D. Stratton



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## LITERATURE REVIEW

### Wildland Fire

#### The Role of Fire

An impressive body of scientific evidence on fire history, fuel accumulation, and fire behavior makes it clear that much of North America is a "fire environment" where wildfire or a substitute recycling mechanism is inevitable. (Arno and Brown 1989, p. 44)

For thousands of years, fire played an integral role in shaping the composition and structure of North American forest, woodland, shrub-land, and grassland ecosystems, particularly in the West (Pyne 1982; Arno and Brown 1991). Mutch (1994, 1995) described the critical role of fire in these ecosystems and lists its functions as follows:

1. Converts dead, organic material to ash.
2. Recycles nutrients.
3. Exposes mineral soil.
4. Restricts some plants and animals and favors others.
5. Regulates plant succession and wildlife habitat.
6. Maintains biological diversity.
7. Reduces biomass.
8. Controls insects and diseases.

In a few areas such as coastal Alaska and some southwestern deserts, fire was a secondary initiator of change. However, over most of the United States fire was the main reason that seral (shade-intolerant) tree and shrub

species remained abundant (Arno and Brown 1991). "Fire also kept shrubs and forests from encroaching into grasslands, and it favored herbaceous species and sprouting shrubs in the semiarid steppes" (Arno and Brown 1991, p. 40).

### **Fire Suppression**

Owing to control efforts of more than half a century, living and dead fuels have accumulated to unnatural and unhealthy proportions. Heavy fuel loads act as "ladder fuels," contributing significantly to severe, uncontrollable wildfires. These conflagrations usually kill even the old-growth trees that survived numerous fires in past centuries and can result in ecosystem simplification, with greater landscape homogeneity and loss of biodiversity (USDA 1996).

Continuing to exclude fire circumvents basic ecological processes (Arno and Brown 1989). Without this "prominent natural disturbance and initiator of successional change" (Arno and Brown 1991, p. 40), fire-frequented ecosystems can be expected to be adversely affected.

It is essential not only for fire managers, but for all resource professionals and the general public to understand fire's historic role, its regimes, and its effects. This knowledge applied on a broad level can restore health to both fire-adapted and fire-frequented ecosystems (Mutch 1994). Not only have suppression efforts adversely affected natural resources, but these devastating fires incur monumental firefighting expenses as well as cost to lives and property.



## The Wildland-Urban Interface

The Western Governors' Association (WGA) has recommended that a national fire hazard and risk assessment system be developed and implemented. The governors believe that "a comprehensive review of fire policy in the wildland-urban interface is critical to preventing future loss of life, property, scenic values, and wildlife habitat" (NFPA 1996, p. 1).

The wildland-urban interface is the transition zone between urban development and the surrounding nonurbanized landscape (Magill *et al.* 1979). They likened this intermingling zone to an ecotone. In plant ecology an ecotone is the transition zone between two plant communities and ordinarily contains plants characteristic of each. "In many respects, the wildland-urban interface is an artificial environment where structures and introduced vegetation are placed in a wildland setting . . . . Almost every part of the nation has a wildland-urban interface problem" (Davis 1990, p. 27).

The wildland-urban interface is not only a transition zone between human development and the wildlands but also a boundary between fire protection agencies. Wildland firefighters are usually not trained or equipped to fight structural fires; likewise, structural firefighters are ordinarily not trained or equipped to fight wildland fires (Anderson 1995).

In addition, structural fire protection in most intermix and some classical interface areas is the responsibility of rural or county fire departments. These fire protection districts are typically comprised of volunteer firefighters with limited training, funding, and equipment. "The result is a great disparity between many

property owners' perceptions and expectations for fire protection and the reality of strategies developed by local fire service organizations" (Close and Wakimoto 1995, p. 180).

When a fire occurs in an interface area, a dual fire protection responsibility is necessary. When priority is given to the protection of life and property, the landscape is usually sacrificed. With firefighting efforts committed to structural protection, the fire is left unchecked and in turn grows and threatens more structures and natural resources.

In Utah, as well as in most of the nation, communities are encroaching into the wildland-urban interface at an astounding rate (Utah Division of Sovereign Lands and Forestry 1995). Citizens seeking peace and solitude move to these areas unaware of the dangers and responsibilities associated with interface living. To homeowners this intermixing zone is a heaven on earth, but for zoning, planning, and fire specialists it is a nightmare. Structures are usually built with highly flammable materials and surrounded by several types of fire-adapted and fire-dependent species.

With the growing acceptance of fire's role, land managers seek to shift fire management from suppression to prescription. But with current reductions in funding, agency downsizing, and the dramatic influx of people moving into the wildlands, fire managers are justifiably hesitant. Compound this delicate situation with more than half a century of fire suppression, and the result is a potentially devastating and often deadly combination. "Neither foresters nor urban firefighters are trained or equipped to cope with fire behavior in this environment"

(Davis 1990, p. 27). Fire specialists are in need of an assessment system that will properly evaluate existing conditions and indicate suitable actions.

## Geographic Information Systems

### Introduction

A geographic information system (GIS) is a computer-based system for managing, manipulating, analyzing, and displaying spatially referenced data. It has the capability to take large amounts of data and perform complex spatial analyses to answer a variety of management-related questions (Burrough 1986; Maguire *et al.* 1991). "As such, it is an ideal tool for wildland fire management planning, which is largely a spatial problem" (Close and Wakimoto 1995, p. 180). Because GIS is commonly used in land management, it can facilitate the sharing and updating of geographic information between resource professionals of different agencies and organizations. This is of particular interest at a time of partnership-building and broad-area-based management (Lucas and Welsh 1997).

### Risk and Hazard Assessments

Most previous models were constructed from a limited number of environmental factors, and human factors were considered only in very few cases. Although wildland fires are clearly a spatial phenomenon, spatial factors were largely neglected in previous fire models, most likely due to the technical difficulty in handling the required tremendous amount of topological information among geographic units. The recent development in vector-based GIS has permitted complicated spatial relationships to be analyzed. (Chou 1990, p. 440)



To date, there are a limited number of GIS assessment models being used in wildland fire management. Chuvieco and Congalton (1989) used vegetation, slope, aspect, elevation, and human risk to derive a wildland fire hazard map for the Mediterranean coast of Spain, an area frequently affected by forest fires. In 1985 the area sustained a severe forest fire. Therefore, a comparison between the predicted hazard and the actual burned area was made. "More than 22% of pixels with high hazard values in the whole study area were burned by the fire, while only 3.74% of those with low hazard values were actually burned" (p. 157).

Chou (1990, 1991) used a GIS to delineate extreme fire danger areas (critical zones). By dividing a management district into geographic units based on specific spatial characteristics and then linking it with a probability model of fire occurrence constructed from logistic regression, critical zones were identified. These zones were then marked for immediate prescribed fires. The principal objective was to create spatial strategies for both prevention and suppression, consequently minimizing costs and losses.

Woods (1991) of California State University developed a fire hazard classification system for chaparral-covered hillsides of southern California. Fire history, fire-line intensity, and the National Fire Danger Rating System (NFDRS) burning index were combined with vegetation, slope, and aspect to create three fire hazard models.

J. van Wagendonk (1990, 1991) in Yosemite National Park likewise used GIS to detect spatial patterns in lightning occurrence, thereby aiding in fire

prediction. He found that lightning strikes were highly correlated with elevation, but not with slope and aspect.

In like manner, McRae (1992) in the Australian Capital Territory used GIS technology to eliminate large irregularities in topography. By so doing, "a meso-scale residual can be used to predict sites that are prone to lightning ignitions" (p. 123). Historical lightning ignitions were then compared with the model. The technique was found to "work very well."

At the University of Montana, Close and Wakimoto (1995) developed a geographic information base for wildland fire hazard assessment and risk analysis. Two levels of resolution were performed, one a "broad-brush" assessment for the entire county and the other a detailed evaluation of a single drainage (Rattlesnake Valley) near Missoula. By combining 10-year fire occurrence data, population density, roads, power lines, and railroads with aspect, slope, and elevation, "mutual threat zones" were identified. Even the location of houses and hydrants, with emphasis on roof types and flow rates, were determined. Rechel *et al.* (1992) conducted a similar study.

Chuvieco and Salas (1994) used topography (slope, aspect, illumination), vegetation (fuel models and flammability categories), and human-caused risk to generate two preliminary maps: ignition risk, which "describes the probability of starting a fire, and behavior risk, which is associated with the spread and intensity of an initiated fire" (p. 7). The combination of these two maps then rendered the final hazard map. This was different from Chuvieco and



Congalton's (1989) earlier work in that several new environmental variables were used and a distinction was made between ignition and behavior risk.

Salazar (1989, 1995), of the Six Rivers National Forest in California, extensively used and encouraged the application of GIS technology in wildland fire management because of its unique capability of integrating huge amounts of fire-related spatial data in an effective and understandable way. Some GIS fire applications include presuppression and suppression activities, fire detection, dispatching crews and equipment, and wilderness fire management.

Recently, an interdisciplinary team of the Boise National Forest (USDA 1996) used a GIS-based risk and hazard assessment to determine the forest ecosystems most at risk of severe fires outside the historical range of variability (HRV).

On the 2.6-million-acre Boise National Forest in southwestern Idaho, severe wildfires have burned nearly 33 percent of the ponderosa-pine-dominated forest over the last six years. Ponderosa-pine-dominated forests are now among the endangered and threatened ecosystems in the U.S. (p. 1)

For this assessment, five submodels were developed: forest vegetation outside HRV, fire ignition, wildlife habitat persistence, watershed hazard (erosion potential), and fish persistence. When these submodels are linked together, the assessment estimates where large, severe fires burning outside the HRV will deplete critical wildlife habitat and accelerate erosion and sedimentation. It is hoped that this assessment will alter the preliminary analysis, which suggests that the "...remaining ponderosa pine forest could be lost within the next 20 years" (USDA 1996, p. 2).

## OBJECTIVE

The objective of this project was to create a wildland fire prediction method (hereafter referred to as an assessment) utilizing GIS and multiple logistic regression. The assessment is to service multiple landscape levels and be useful to land managers, particularly in the wildland-urban interface.

## LOCATION OF STUDY

The study area encompassed the Logan Ranger District, Wasatch-Cache National Forest and adjacent state, county, and private lands (northeastern Utah). It extended from the western boundary of the Wellsville Wilderness Area east to Bear Lake and north from Blacksmith Fork Canyon, terminating at the Utah-Idaho border (Figure 1). It was approximately 200,000 hectares of steep, rugged terrain ranging in elevation from about 1,200 to 3,000 meters. The area is subject to heavy winter snowfall and intense summer thunderstorms, which lead to high runoff. The vegetation is principally grasses, brushes, mountain shrubs, and juniper (*Juniperus* spp.) in the lower elevations with fir (*Abies* spp.), Engelmann spruce (*Picea engelmannii* Parry ex Engel), lodgepole pine (*Pinus contorta* Dougl. ex Loud), and aspen (*Populus tremuloides* Michx) in the higher elevations.

Three counties were represented in the study area, Cache, Rich, and Box Elder, with the greater part (about 80%) in Cache County. The bulk of the residents live in the Cache Valley, with a few residents scattered in or adjacent to forested areas. The area contains commercial zones, subdivided and agricultural areas, and two federally designated wilderness areas. Land ownership is mostly private in Cache Valley, and primarily federal and state in the surrounding mountainous areas.

The area was well suited for the implementation of this proposed fire assessment. Not only does it possess diverse social and environmental



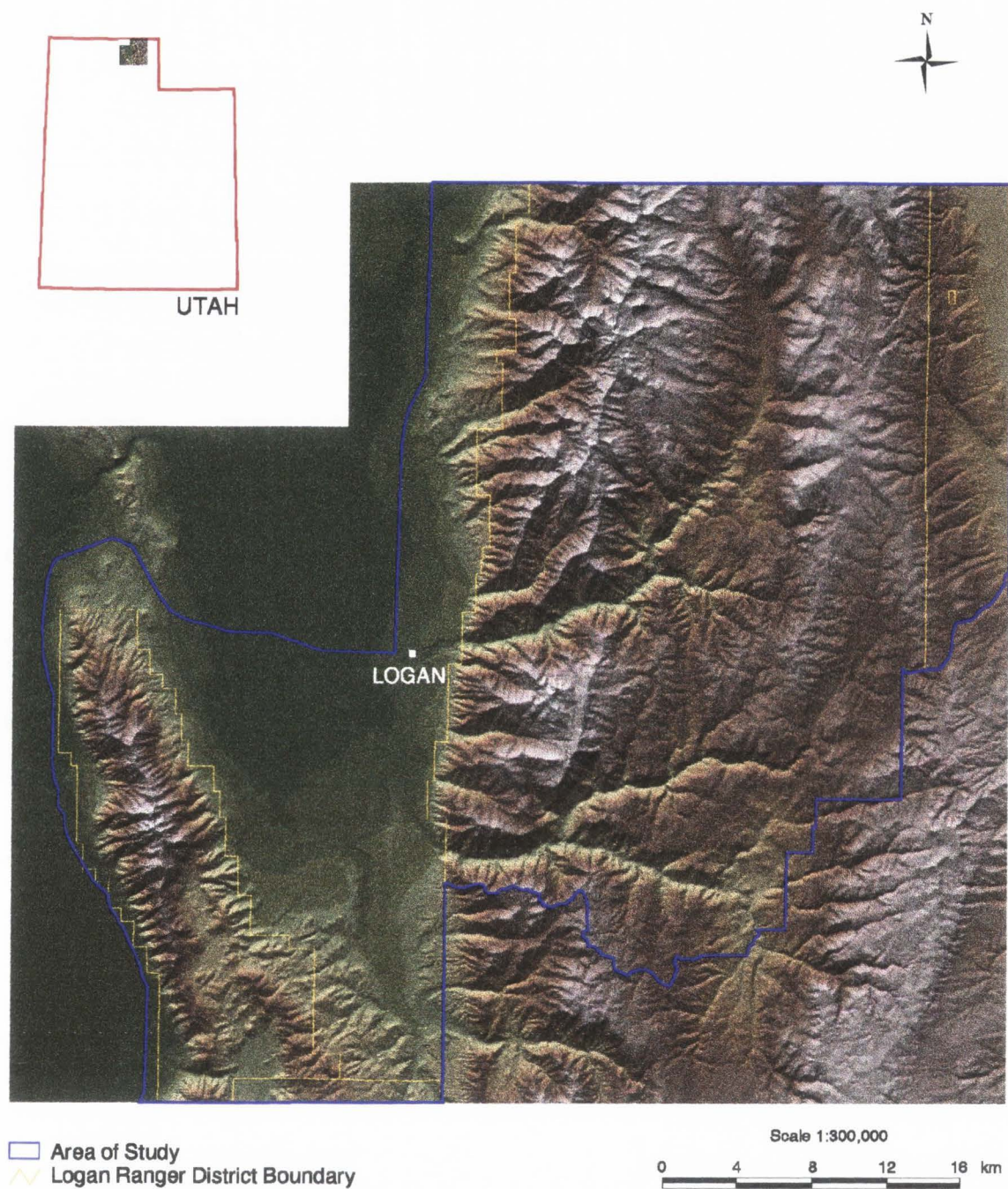


Figure 1. Painted relief of study area vicinity, northeastern Utah.

conditions, but the wildland-urban interface is currently at manageable levels. However, this will not last long because of the tremendous growth the area is experiencing (BEBR 1993).

In anticipation of this growth, several cities and Cache County are revising their master plans. In some cases, proposed revisions include recommendations by fire chiefs for adoption of fire ordinances in wildland-urban interface areas. A comprehensive fire ordinance based on high and critical fire danger areas will enable the community to be better prepared for future fires and development.

## METHODS

### Gathering and Construction of GIS Data

Creating a fire assessment model requires consideration of a variety of topographic, environmental, climatic, and human variables. Weather, fuel, and topography are the main factors constituting the fire environment (Deeming *et al.* 1978). In addition, roads, recreational areas, and housing developments are important components identifying probable human-caused ignition and protection areas (Figure 2).

These factors can be grouped into GIS "themes," namely, topography, infrastructure, vegetation, climate, "sensitive" natural values, and fire history. They represent a conglomeration of single or multiple GIS data overlays or layers. By identifying these assessment variables, areas of risk (ignition exposure), hazard (potential to burn), and value (protection areas) can be defined (Pyne 1984). ARC/INFO version 7.0.4 and 7.1.1, ArcView version 2.0, 3.0a and b, and ArcTools version 7.1.1 developed by the Environmental Systems Research Institute (ESRI) of Redlands, California, were used to create, analyze, and prepare GIS data for modeling.

#### Topography

Topographic data were obtained from digital elevation models (DEMs). These DEMs consist of "a regular array of elevations referenced horizontally in the Universal Transverse Mercator coordinate system" (USDI 1990, p. 2) and to



## GIS DATA LAYERS

Roads and Trails  
Historic and Recreational Sites  
Summer and Permanent Homes  
Other Structures  
Lightning Occurrence

Slope  
Aspect  
Elevation  
Precipitation  
Temperature  
Vegetation  
Solar Radiation

Soils  
Old Growth  
Wildlife Habitat  
Municipal Springs  
Cultural Resources  
Watershed Boundaries  
TES Flora and Fauna Habitat  
Historic and Recreational Sites  
Summer and Permanent Homes  
Other Structures

## GIS THEMES

**RISK AREAS**  
**(Ignition Exposure)**

**HAZARD AREAS**  
**(Potential to Burn)**

**VALUE AREAS**  
**(Protection Areas)**

Figure 2. Data considerations for a wildland fire assessment.

the North American Datum of 1927. The unit of coverage is the 7.5-minute quadrangle with "data stored as profiles in which the spacing of the elevation along and between each profile is 30 meters" (USDI 1990, p. 3). The individual quadrangles (1:24,000) that provide coverage for the study area were merged using ARC/INFO (Swiatek 1997). Elevation breaks were in approximately 150-meter increments, beginning at 1289 meters and terminating at 3030 meters (see Figure 24 in Appendix A).

Slope was likewise derived from the DEM by calculating each 30-meter cell from the 3 x 3 neighborhood using the average maximum technique (Burrough 1986). Slope was expressed in percent, as defined by the ARC/INFO ARC Command Manual, where the maximum percent slope is infinite. This should not be confused with slope defined in degrees where the maximum is 90 degrees. Slope values ranged from 0% to 605% and are distinguished by six classes (see Figure 25 in Appendix A).

Aspect (slope direction) was also calculated from the DEM, into nine classes (based on the eight cardinal points and flat). Aspect was measured beginning at north and moving in a clockwise direction, being expressed in positive degrees from 0 to 360. Areas with no aspect (flat) are assigned a value of -1 (see Figure 26 in Appendix A).

## **Infrastructure**

The infrastructure theme contains planimetric data derived from cartographic feature files (CFFs) (USDA 1993). From the CFF data a variety of



GIS layers were developed including roads, trails, land status and ownership, and historic and recreational sites (see Figure 27 in Appendix A). Because of the continual population growth and the importance of precision in identifying interface areas, a global positioning system (GPS, Trimble Geo Explorer II) was used to delineate these areas.

For the most part, Cache Valley and the west side of Bear Lake were the major interface areas. There are a number of summer homes in the canyon areas, but these are in close proximity to main roads and waterways. Furthermore, any isolated dwellings or other structures not in the areas discussed above or in the CFFs were mapped with the GPS. GPS data were then downloaded, corrected, and a coverage constructed.

Also contained within the infrastructure theme is a cultural resources layer obtained from the Wasatch-Cache National Forest supervisor's office in Salt Lake City, Utah. This "sensitive" layer identifies known archaeological sites of interest. This information was originally mapped out by Forest Service biologists and archaeologists and then later digitized to create a GIS coverage.

## **Vegetation**

Because vegetation is influenced by topographic and climatic variables, it plays a crucial role in modeling and determining fire behavior and spread. An ideal vegetation coverage would contain attributes such as horizontal continuity, vertical arrangement, fuel loading, canopy closure, and species. Due to the limitations of remotely sensed data and the complexities of creating such

a coverage, most flora layers consist of vegetation or cover type, density, and possibly canopy closure.

The cover-type layer was obtained from the Wasatch-Cache National Forest. It was created from high-resolution Landsat Thematic Mapper imagery. Seventy-five "spectral classes" were visually regrouped into vegetation classes by examining them and using 1:20,000 color aerial photos, orthophotoquads, and professional familiarity with the area (see Figure 28 in Appendix A).

Initial field testing indicated that the classification distinguished well between forest and nonforest types (i.e., aspen and conifer and sagebrush or grass). Since the purpose of the layer was to provide sufficient detail for mid- to broad-scale planning and analysis (the minimum map unit size is 2 hectares), vegetation classes were left as cover types rather than individual species. Attributes contained within the vegetation layer include cover type, growth form, and density (USDA 1995).

One substantial change to the original cover-type layer was the creation of a new class, conifer mortality, which was based on aerial detection surveys. An 11-year period of data (1984-1995) were obtained from the USDA, Forest Service, Forest Health Protection (Boise, Idaho), and bark beetle mortality areas were overlaid with the existing cover-type layer. Areas of mortality that occurred among mixed conifer, conifer-aspen, spruce-fir, Douglas-fir, and lodgepole pine were selected and reclassified as "conifer mortality." Note: Aerial detection surveys are not conducted in wilderness areas.

## Climate

Four GIS layers constitute the climate theme: precipitation, temperature, solar radiation, and lightning occurrence. The precipitation and temperature grids were obtained from Dr. Donald Jensen of the Utah Climate Center, located at Utah State University. These GIS layers contained the average annual precipitation and temperature for the past 30 years (1961-1990) (see Figures 29 and 30 in Appendix A).

Precipitation and temperature measurements were acquired from a network of manual and automated weather stations located in or near the study area. The GIS grids were developed using these data and a space-time average, where the data were first averaged in space and second in time. An iterative algorithm, using a minimum curvature technique, was used for best fit (Swiatek 1997). The initial cell size of the precipitation grid was 100 meters. To properly overlay the precipitation grid with other layers, it was resampled to 30 meters using a cubic convolution resampling algorithm, where the new value of each cell is based upon the weighted distance average of the 16 nearest input cells (ESRI 1994).

Next, there are several methods available to compute solar radiation using techniques developed by Swift (1976), Dubayah and Rich (1995), and Kumar *et al.* (1997). Because of the consideration of direct insolation (including the effects of topographic shading) and the ease of running the SOLARFLUX program in ARC/GRID, the Dubayah and Rich (1995) model was selected.



SOLARFLUX uses input of a topographic surface, specified as a GRID of elevation values, as well as latitude, time interval for calculation, and atmospheric conditions (transmittivity), and provides output of direct radiation flux, duration of direct radiation, sky view factor, hemispherical projections of horizon angles, and diffuse radiation flux for each surface location. (p. 413)

Solar radiation was computed hourly for 7 days (June 15, July 1, July 15, August 1, August 15, September 1, September 15). Figure 31 in Appendix A exhibits the grid created from the SOLARFLUX model by running the ARC/GRID SOLARFLUX AML.

Lastly, the frequency of lightning strikes is positively correlated with elevation and can exhibit spatial patterns caused by climatic and topographic variables (van Wagtendonk 1990, 1991). In this study area, 46% of the fires were naturally caused. Therefore, if lightning strikes could be recorded, areas of greatest lightning occurrence would be identified.

Global Atmospheric Inc. (GAI) of Tucson, Arizona, owns and operates the National Lightning Detection Network (NLDN), the most sophisticated lightning and location detection system in the world. This state-of-the-art system provides reliable, cost-effective data to a variety of customers. The NLDN consists of over 100 remote, ground-based sensing stations that monitor cloud-to-ground discharges and transmit data via satellites to a control center. This makes possible an accuracy of about 500 meters throughout the continental U.S. (GAI 1996).

The Bureau of Land Management has a similar system, the Automated Lightning Detection System (ALDS). However, the ALDS system has been

operational for more than 30 years and in that time, few improvements have been made. Because of this the ALDS localizing accuracy is limited to over 1 mile (Kridner *et al.* 1980). Moreover, although the ALDS system's data is accessible, the network has recently been taken offline. Because of all of these factors, the NLDN was used.

The only drawback to using Global Atmospheric's data is that the company has only been operating for 2 years. A 10-year period is ideal when mapping lightning cycles; however, 2 years of lightning data was better than less accurate data, or none at all (Geitz 1997; van Wagendonk 1997). From this data, a GIS point coverage was constructed. Lightning strikes were plotted in the study area, and a density grid identifying the most active areas was created (see Figure 32 in Appendix A).

### **"Sensitive" Natural Values**

This theme consists of threatened, endangered, and sensitive (TES) flora, TES wildlife habitat, old-growth forests, municipal springs, visual quality objectives (VQO), and soils (landtypes) (see Figure 33 in Appendix A). TES flora, wildlife habitat, VQOs, and old-growth areas were obtained from the records of the Wasatch-Cache National Forest.

There are a number of municipal springs located in the study area on both state and federal lands. These springs typically provide water to local communities. The municipal springs' coverage was created in cooperation with

city, county, and state planning and engineering offices. Municipal springs were identified on a variety of maps and digitized to create a coverage.

Land-type association coverage from the Wasatch-Cache National Forest was created from a combination of published county soil surveys and unpublished contracted soil resource inventories at the order 3 level of survey. It is common after a fire has occurred in mountainous terrain to experience erosion and periodic mass wasting (Evenstad and Rasely 1995).

By working closely with the forest soil scientist, land types of greatest erosion potential were identified. The soil coverage was converted from a polygon coverage to a grid and combined with a slope grid to produce a final map (see Figure 34 in Appendix A). This final grid shows any area that might have erosion potential after a moderate to severe fire. This layer is useful to land managers who must preserve soil, vegetation, and scenic values (King 1992), as well as protect wildland-urban interface areas.

The "sensitive" natural value theme was not created to construct the fire probability model; rather it serves as a layer for managers to overlay on probability grids to identify priority areas (critical fire danger areas).

## **Fire History**

Fire occurrence data available from the Wasatch-Cache administration covered a period from 1958 to 1996. Fire reports from the Utah Division of Forestry, Fire, and State Lands (including county and private lands) were from



1968 to 1996. Errors in fire reports are common when constructing fire histories (USDA 1996). Because of this, fire reports (particularly locations, dates, and causes) were intensively reviewed. Reported fire locations were compared with existing conditions and rechecked with state, county, and district fire specialists, to provide the most precise database. Minor errors were discovered, usually in reporting fire "legals" (township, range, section, subsection).

Legal descriptions were usually reported by quarter, quarter section, but for fires not reported to this detail, local fire managers usually pinpointed fire locations. When accurate fire locations for quarter, quarter sections could not be determined fires were omitted. The result was 390 fires on federal land and 210 occurring on state, county, and private lands (see Table 2 and Figure 36 and 37 in Appendix B). Fires were plotted down to the quarter, quarter section (the center point of the smallest quarter, quarter section, chosen as the center point for the fire) (see Figure 35 in Appendix A).

### Original Assessment Methodology

It was first thought that all fire and topographic characteristics could be obtained from fire reports. This information would be entered into the GIS database for building the matrix in ranking layers and determining high and critical fire danger areas (Figure 3). If areas of ambiguity were found, the literature would be used to remedy the problem.

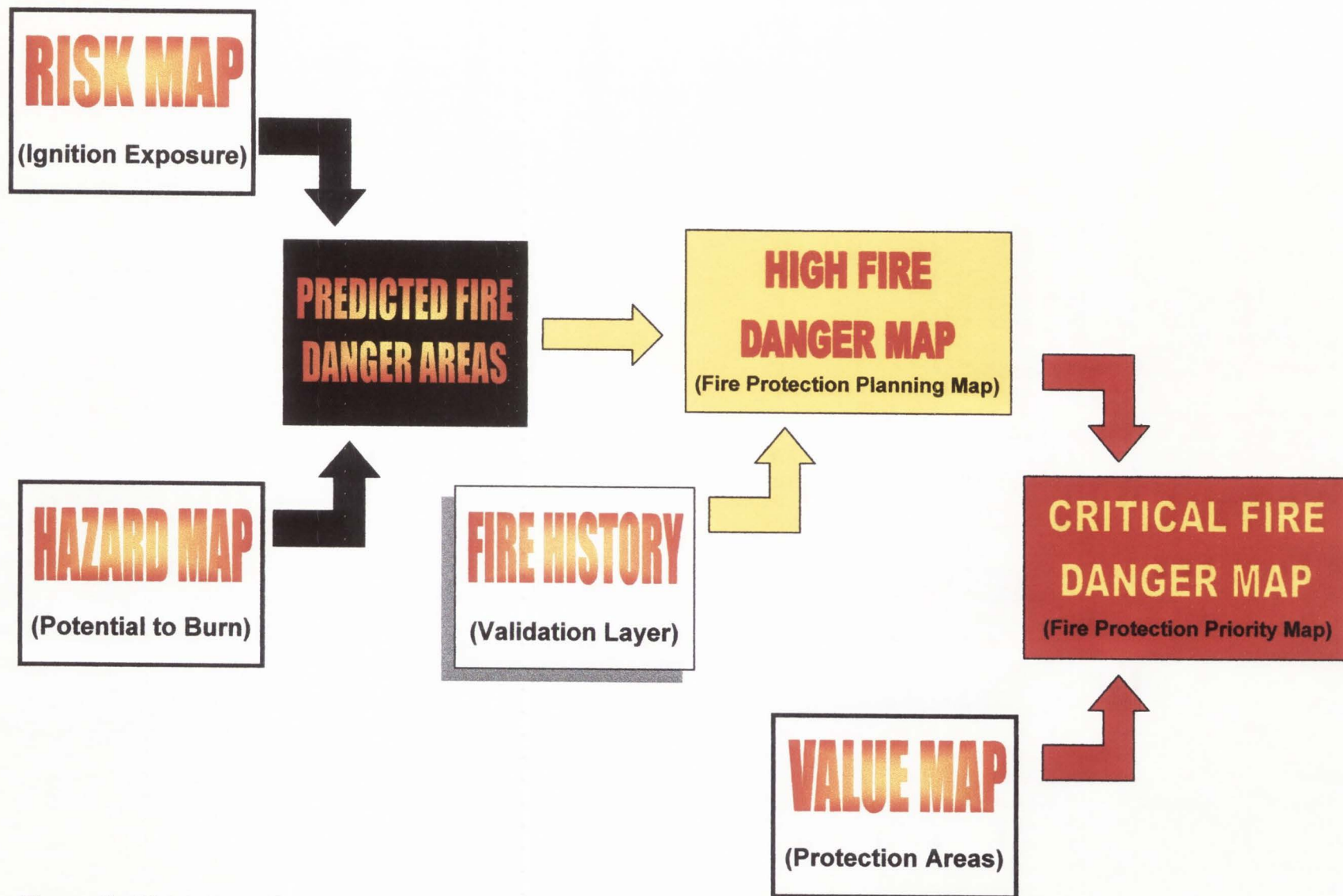


Figure 3. Flow chart of original fire assessment methodology.



While reviewing fire records, it became apparent that fire reports from different agencies varied considerably (Appendix C). For example, the older Forest Service fire reports recorded topographic information such as slope, aspect, elevation, and position on the slope, as well as vegetation characteristics such as fuel type, cover-type, and timber-type. The state fire reports, which included county and private wildland fires, formerly recorded most of these valuable specifics, but now make little or no mention of them. Forest Service fire reports have shifted from detailed reporting of fire characteristics to economic issues.

Furthermore, discrepancies in reporting the same fire characteristics occurred frequently between agency personnel. For instance, slope was reported in both percent and degrees. In most cases a number was given but a unit was not specified. Another common problem was in reporting the vegetation type. The word "brush" was often used to represent a wide range of vegetation types, including sagebrush, oak brush, mountain-mahogany, and maple.

To compound the problem, while researching the literature on fire and its interactions with topographic and environmental factors (i.e., slope, aspect, vegetation, etc.), professionals frequently disagreed. This was partly due to the differences in climate, topography, and vegetation experienced from one location to another.

Also, even though the procedure outlined in Figure 3 seems conceptually sound, when marrying wildland fire knowledge with GIS needs and limitations,

many questions surfaced. The difficulty came when creating the usually broad classifications necessary to build an assessment ranking matrix, while still retaining the importance of the data from a wildland fire perspective.

For example, to create the hazard map (potential to burn), vegetation categories must be constructed based on fire spread. This may be a simple task when classifying bottomland hardwoods or a wet meadow, but it is more difficult to classify juniper, oak brush, or conifer species. The classification becomes even more difficult with respect to aspect. Literature is divided between most fires occurring on south aspects versus southwest aspects. Yet in this study area, fires have historically occurred most frequently on west aspects. Is this result explained by the greater occurrence of west aspects, or is there a combination of factors contributing to this tendency, or perhaps both?

Similar problems are found for most of the hazard layers and again when bringing risk and hazard areas together. In short, it became extremely difficult to create a matrix that properly evaluated risk and hazard areas while still being objective and meaningful from a fire management standpoint. What was impractical became impossible when trying to make this assessment suitable for multiple landscapes, which inevitably have different topographic, environmental, and human factors. Accordingly, a substantial change in the original assessment methodology resulted.

It is worth noting that to go ahead and build on the original fire assessment methodology would be a serious error. By simplifying the complex interactions

between human, environmental, and topographic characteristics, the assessment quality is compromised. This is a classic example where unsound methods can only lead to poor management; quoting from Romesburg (1985):

Unreliable knowledge is the set of false ideas that are mistaken for knowledge. If we let unreliable knowledge in, then others, accepting these laws, will build new knowledge on a false foundation. At some point an overload will occur, then a crash, then a retracting to the set of knowledge that existed in the past before the drift toward unreliability started. (p. 249)

This statement has particular importance to a GIS assessment such as this. Like other technologic advances, one must be careful not to camouflage unsound practices or unreliable science with remarkable utility and convincing power of GIS.

#### Final Assessment Methodology

Owing to the issues mentioned above, it was decided to use historic fire locations to sample GIS data layers. It is better to let fire data, although at times incomplete, dictate which environmental and human factors resulted in a fire, rather than the subjectivity and potential unreliability of fire managers. Output from this procedure could then be used to build the matrix necessary to delineate areas of high and critical fire danger.

Originally only one assessment methodology would be developed to service multiple landscapes. As the project progressed, it became apparent that one method would not be suitable. If more than one assessment procedure was presented, the process could accommodate a wide array of agencies, needs, and landscapes.



This study utilized one wildland fire assessment methodology with two phases. These fire danger approximations can be thought of as two separate phases of analyses each with distinct methods and operations

## **Phase 1**

The purpose of this type of assessment is to provide a quick and fairly reliable analysis for planning at a landscape level (e.g., state, region). Fire density grids are created based on historic fire locations (the fire history layer), thus delineating high fire danger areas and alerting managers to areas requiring further attention. Ideally, this crude assessment will act as a preliminary analysis to narrow the focus for a phase 2 study. This assessment's usefulness is limited in such a small area; nevertheless, it was done to provide a pattern.

### Phase 1 Design

Two factors that are critical for the phase 1 assessment are accuracy in reporting and plotting fire locations and length of the fire history. As stated earlier, the fire history layer was created by plotting fires based on locations in fire reports (usually recorded using the U.S. Public Land Survey System). Since fire locations are the only variable used in this assessment, it becomes crucial that fire reports be carefully reviewed.

The main objective was to plot the fire down to the most accurate division (e.g., section, subsection, etc.). For this assessment method, a precise larger area (e.g., a section) is as meaningful as an actual fire location. Personal



experience, fire names compared to the surrounding area, and other fire information on the fire report can aid in verifying the location.

Not only was accuracy in reporting fires paramount, but the length of time the fire history covers is critical. As a general rule, the more fires the fire history layer contains, the greater will be the likelihood of a pattern emerging. Because statistical methods are not used in phase 1, it is important that the reporting periods between agencies be equal to avoid bias toward any particular area or agency.

### Phase 1 Operations

Using the fire history layer, density grids were created with ESRI software ArcView 3.0a, Spatial Analyst extension. The "simple" density method was chosen where the density for each cell is calculated by "summing the value found in the population field for each point found in the search radius and dividing by the area of the circle in area units" (ESRI 1997).

### **Phase 2: Creation of the Fire Probability Model**

Phase 2 models the relationship between wildland fires and environmental and human variables by combining GIS data layers and analyses with multiple logistic regression. It is best suited for relatively small to moderately sized areas, but can address issues at the landscape level in conjunction with the phase 1 assessment. The outcome of phase 2 is multiple fire prediction layers, with lower, predicted, and upper limits, delineating areas of fire occurrence probability.

## Phase 2 Design

GIS layers and attribute data used in the Phase 2 analyses were slope, aspect, elevation, precipitation, temperature, vegetation (cover type), lightning strike density, land ownership, and fire history (including distance to roads and trails, cause, and date of ignition). All vector layers were converted into raster data or grids (data stored as 30-meter-square cells).

Using the "zonalmajority" command in ARC/GRID, each fire was given an average value based on the quarter, quarter section it occurred in for each of the grids listed above. In order to use multiple logistic regression, a random sample of 600 points was taken from the study area for comparison.

Using the ARC/GRID "sample" command, the independent variables were sampled for the 1,200 points (see Figure 8 on page 40). This generated a text file containing 1,200 rows, each row with an observation number, an easting (x) and a northing (y) (the fire location or random point), and discrete information for that location (Appendix D).

With the aid of the Rocky Mountain Research Station, at Logan, Utah, research statistician Dr. David Turner processed the sample data to determine which statistical procedure was most effective. After experimenting with a variety of statistical analysis techniques, it was determined that multiple logistic regression yielded the best fit for modeling fire occurrence given the predictor variables provided in the sample.

The goal of any logistic regression model building technique is to find the best-fitting and most parsimonious, yet biologically reasonable model to describe the relationship between an outcome (dependent or response variable) and a set of independent (predictor or explanatory) variables. (Hosmer and Lemeshow 1989, p. 1)

Therefore, regression is used (1) to determine if a relationship exists between two numerical variables,  $x$  and  $y$ , and (2) for the prediction of  $y$ . The dependent or response variable ( $y$ ) is the phenomenon whose level or presence is to be predicted or explained for each location in a study site, in this case a fire occurrence. The independent or explanatory variable ( $x$ ) is the known attributes of the location, i.e., slope, aspect, elevation, etc. (ESRI 1996). Multiple regression is used when there is more than one independent variable (Hosmer and Lemeshow 1989).

In constructing a fire probability model, we know of locations where fires have and have not occurred. By using the GIS sample data, logistic regression can determine the relationship between the attribute data at fire and nonfire locations. From this information a fire probability model can then be constructed to predict a fire at an unsampled location.

#### Phase 2 Operations:

Because the Wellsville Range (on the west) and the Bear River Range (on the east) have fairly distinct characteristics, the study area was separated into two data sets. Furthermore, fires were separated by whether they were human- or lightning-caused. This separation proved very useful in developing

the model. Also, because Forest Service fire reports went back nine years further than other fire records, the date of the fire and ownership was analyzed. Finally, a step-wise, backward selection method was performed using S-Plus 4 (S-Plus 4 1997).



## RESULTS

### Phase 1

The output of the phase 1 assessment is shown in Figures 4-6, which were created using ArcView Spatial Analyst. Density grids from this procedure indicate where high fire danger areas are. Though only based on fire locations, these fires are a response of environmental, topographic, and human factors (e.g., ignition source, elevation, and temperature).

### Phase 2

Using the explanatory variables for the regression, trends can be analyzed with scatter plots. Figure 7 represents scatter plots of the data. The smooth lines in the middle of each panel are the LOWESS smooth. LOWESS stands for locally weighted regression scatter plot smoothing (Cleveland 1979, 1981) and "LOWESS employs weighted least squares, which is a statistical method that can be used to fit a line to a set of points on a scatter plot" (Chambers *et al.* 1983, p. 94). The y axis represents the probability of a fire with the x axis as the predictor variable. A flat line (as in the case with the random number-"RNO") represents no relationship. Lines should be interpreted with care because there is no confidence interval.

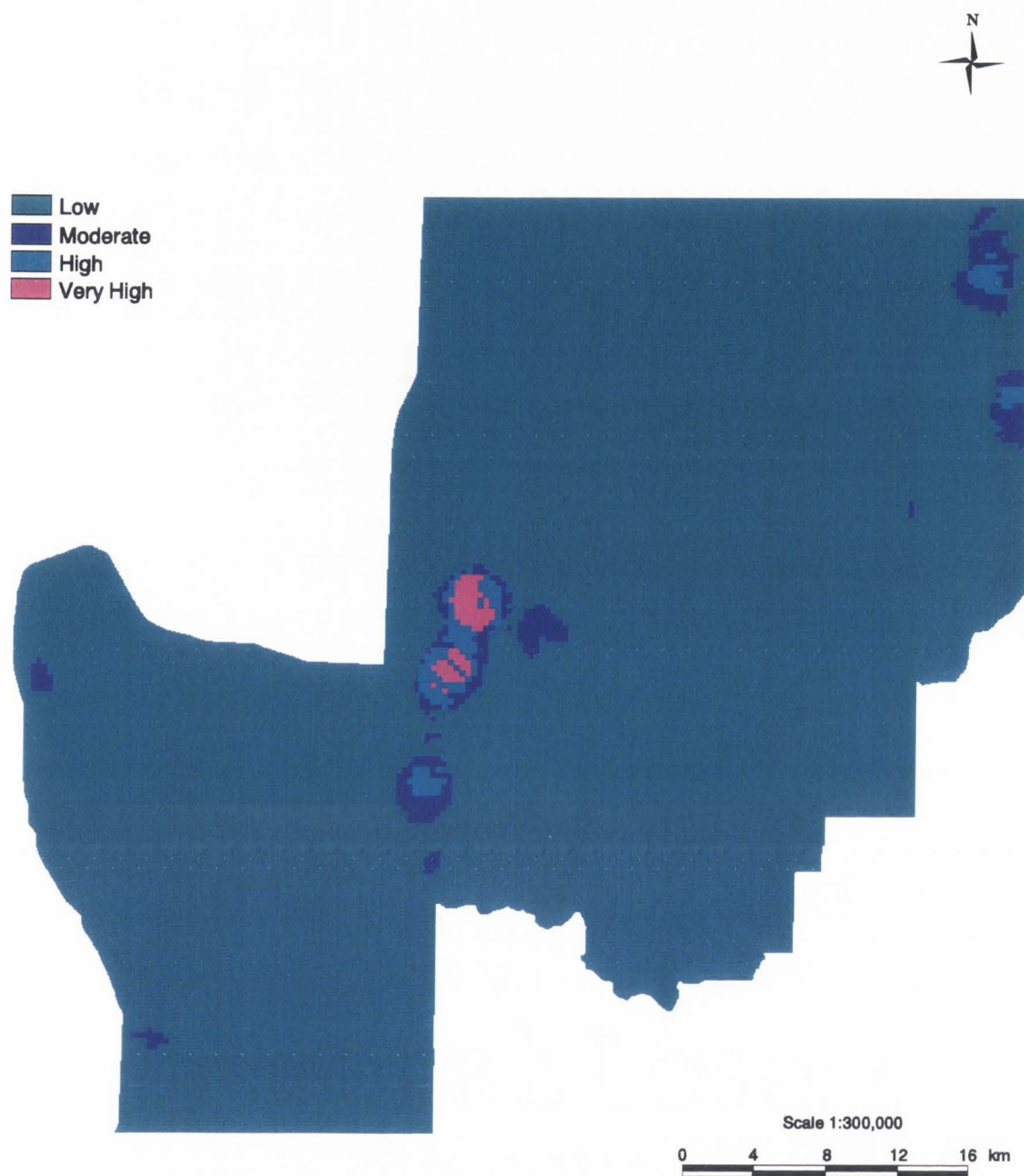


Figure 4. Phase 1 human-caused fire density map.

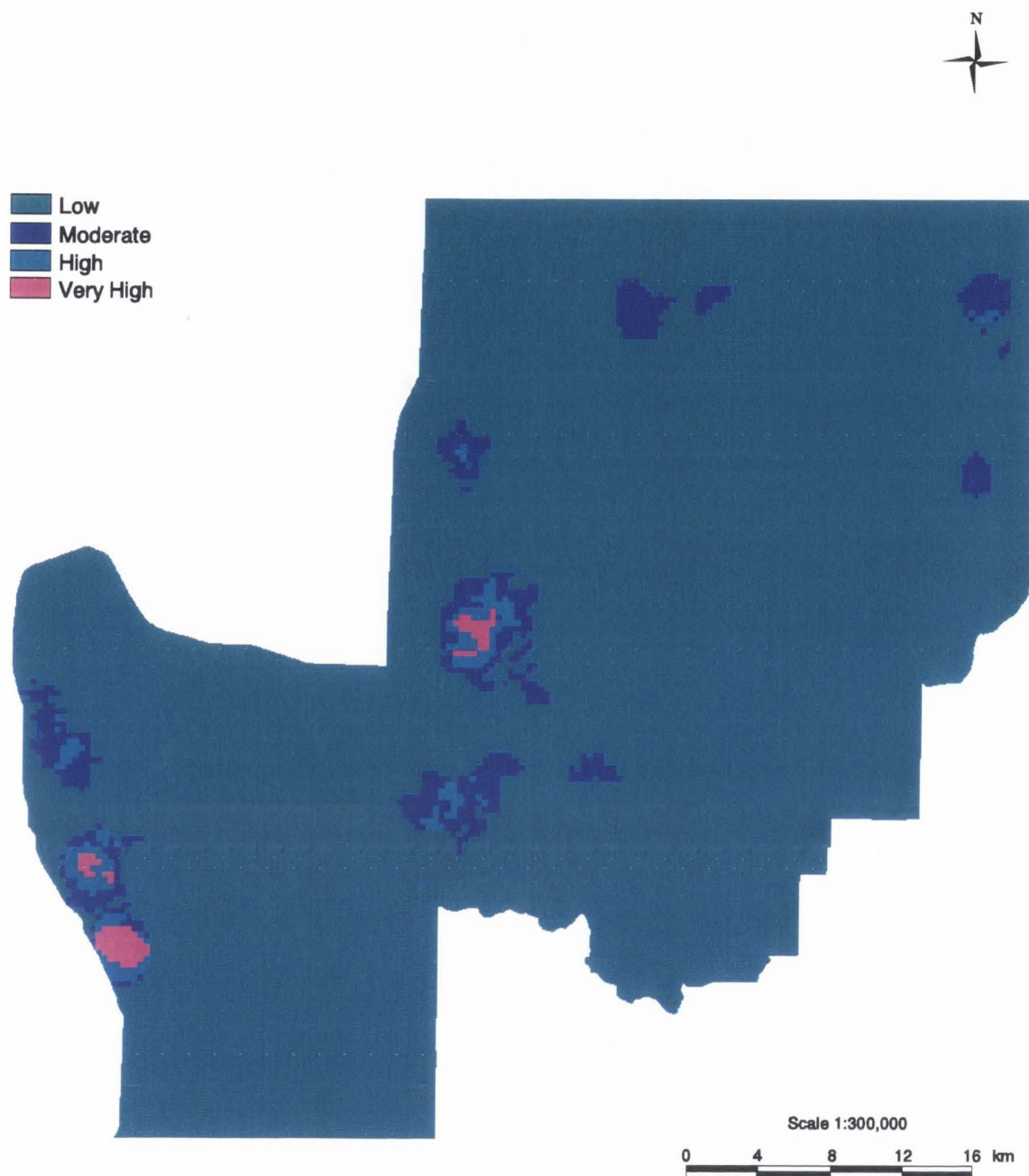


Figure 5. Phase 1 lightning-caused fire density map.

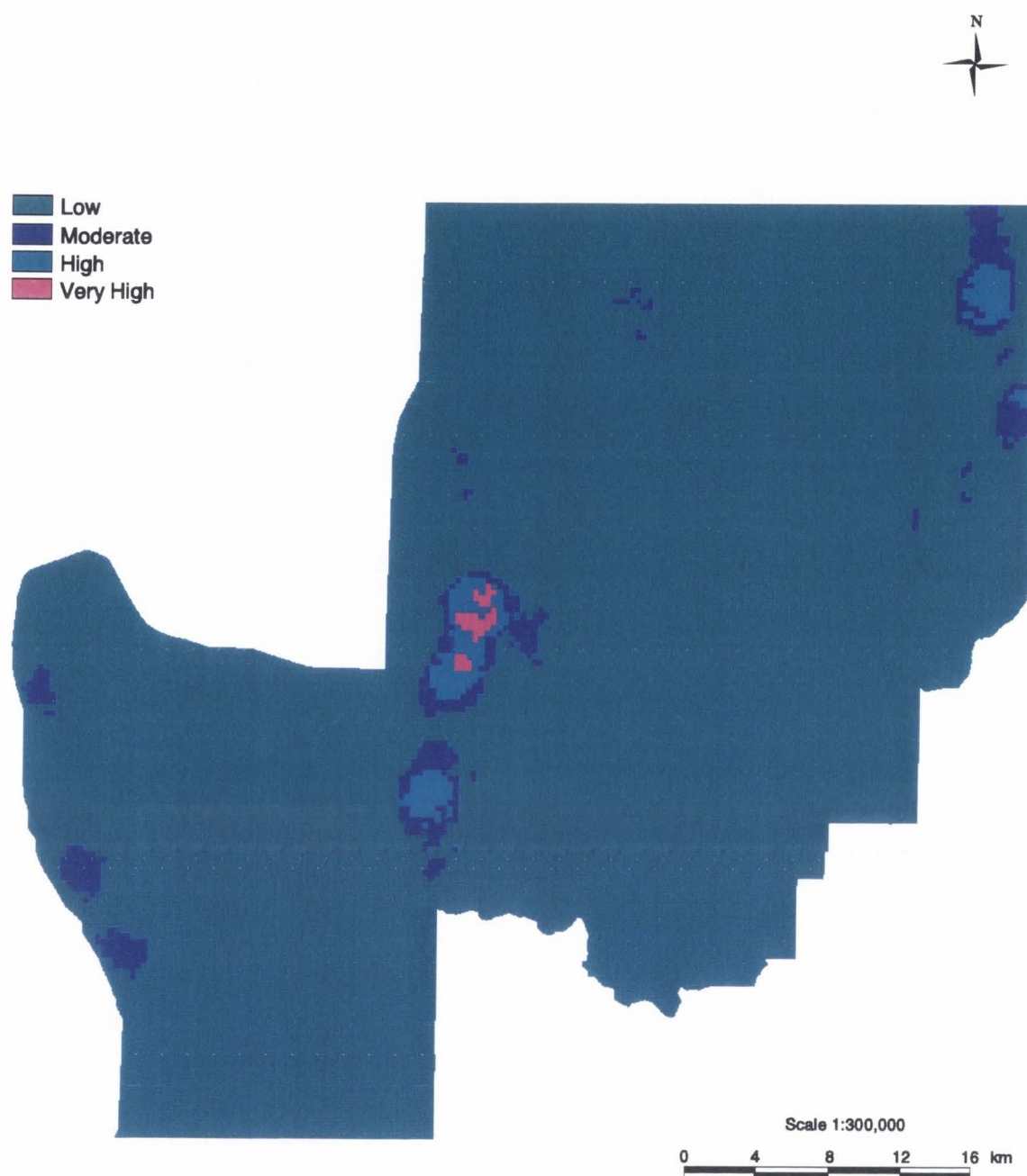


Figure 6. Phase 1 human- and lightning-caused fire density map.



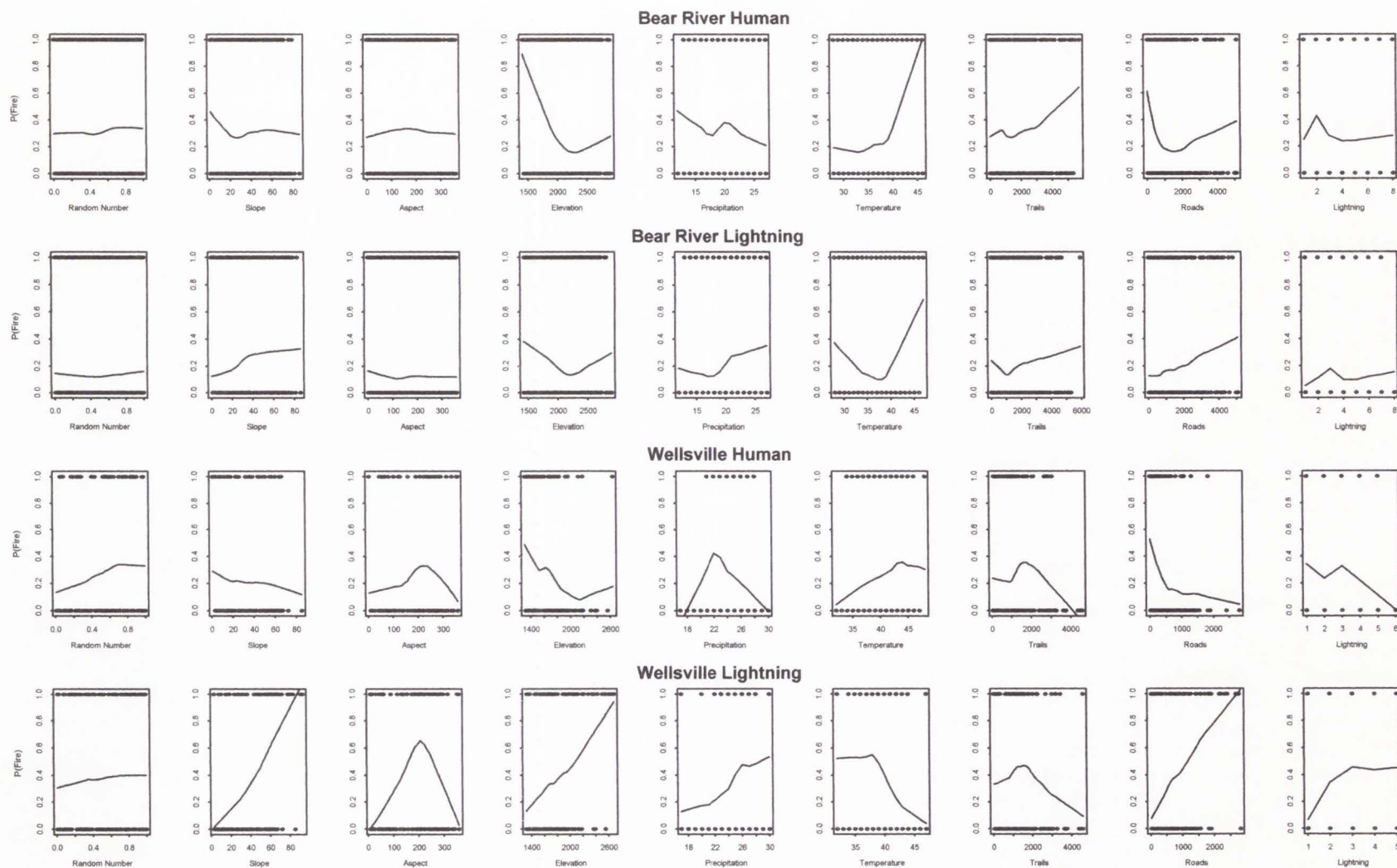


Figure 7. Scatter plots of Bear River and Wellsville data sets. The top line represents the fire points, the middle curve is the LOWESS smooth of the relationship, and the bottom line represents the random points.

Table 1. List of logistic regression coefficients for the four data sets by explanatory variable.<sup>1</sup> Independent variables not significant at the  $\alpha=.05$  level are denoted by "-".

|                                 | Human-Caused Fires |                   | Lightning-Caused Fires |                   |
|---------------------------------|--------------------|-------------------|------------------------|-------------------|
|                                 | <u>Bear River</u>  | <u>Wellsville</u> | <u>Bear River</u>      | <u>Wellsville</u> |
| <b>Predictors</b>               |                    |                   |                        |                   |
| Y-intercept                     | -1.22              | 6.89              | -27.43                 | 77.5              |
| Slope                           | -                  | -                 | -0.193                 | 0.0485            |
| Aspect                          | -1.93              | -                 | -                      | -                 |
| Elevation                       | 5.05               | -0.0042           | -                      | -                 |
| Precipitation                   | -                  | -                 | 1.28                   | -3.17             |
| Temperature                     | 4.24               | -                 | 0.608                  | -1.61             |
| Solar Radiation                 | -                  | -                 | -                      | -                 |
| Trails                          | -                  | -0.0006           | -                      | -                 |
| Roads                           | -3.28              | -                 | -                      | 0.0148            |
| Cover-type                      | -                  | -                 | -                      | -                 |
| Lightning                       | -                  | -                 | -                      | -                 |
| Date of Fire                    | -                  | -                 | -                      | -                 |
| Ownership                       | -                  | -                 | -                      | -                 |
| <b>Interactions<sup>2</sup></b> |                    |                   |                        |                   |
| Slope:Temp                      | -                  | -                 | 0.0053                 | -                 |
| Precip:Temp                     | -                  | -                 | 0.03                   | 0.063             |
| Elev:Roads                      | 1.27               | -                 | -                      | -                 |
| Elev:Temp                       | -1.85              | -                 | -                      | -                 |
| Temp:Roads                      | -                  | -                 | -                      | -0.0004           |

<sup>1</sup> Comparisons can be made vertically but cannot be made horizontally because of different data classes and scales.

<sup>2</sup> All interactions were examined; only significant ones are listed.

The stepwise, multiple logistic regression procedure yielded the coefficients shown in Table 1. Coefficients in the table were used to get the predicted logits for the various values of the explanatory variables.

To compute the logits, the model is analyzed in the logit scale where the relationship is assumed to be linear. This was done because the linear scale is much easier for prediction and analysis. The first step was to compute the logit.

$$\hat{\text{logit}}_j = \ln(\pi_j / (1 - \pi_j)) = \beta_0 + \beta_1 X_1 + \dots + \beta_k X_k,$$

where  $\pi_j$  is the probability of a fire, and is initially estimated by  $\pi_j = (f_j / n_j)$

$f_j$  = number of fires occurring at a given class of the predictor variable

$n_j$  = total number of points (random and fires) in a given class for a particular predictor variable

$\beta_i$  = coefficient for the  $i^{\text{th}}$  predictor variable

$\beta_0$  = y-intercept in logit scale

The variables  $X_1, \dots, X_k$  are the independent or predictor variables used to model the fire response. The logit is then back-transformed to compute the predicted probability of a fire, expressed as  $P(\text{fire}) = \pi$ .

$$\pi = P(\text{fire}) = e^{\text{logit}} / (1 + e^{\text{logit}})$$

The relative importance of candidate variables is used in a backwards, stepwise procedure to select a final model. For instance, the final model for predicting the logit for a human-caused fire in the Wellsville data set is:

$$\hat{\text{logit}} = 6.8942386467 - 0.0042022479(\text{elev.}) - 0.0005605473(\text{trails}).$$

Note: Elevation and trails were found to be significant in predicting a human-caused fire in the Wellsville data set; thus coefficients from the regression are used in the formula to transform the logit (see Table 1).

For example, if the elevation at a specific location is 1,453 meters and the nearest distance to a trail is 4583.313 meters, the predicted logit would be:

$$\begin{aligned} \hat{\text{logit}} &= 6.8942386467 - 0.0042022479 * 1453 - 0.0005605473 * 4583.313 \\ &= -1780791, \end{aligned}$$



making the predicted  $P(\text{fire} \mid \text{elev.}=1453, \text{trails}=4583.313) = e^{-1.780791} / (1 + e^{-1.780791}) = 0.1442055$ .

Formulae to compute the standard error of the predicted logit (denoted  $se(\text{logit})$ ) are reported as calculated by the S-plus 4 program (S-Plus 4 1997). For the example calculation, the estimated standard error of the predicted logit is 0.659993, for an elevation of 1453 and nearest trail distance of 4583 meters.

The predicted logit and its standard error are used to produce 95% confidence intervals for the logit by adding and subtracting twice the estimated standard error from the predicted logit. For the example above, this generated a confidence interval of predicted logit  $\pm 2 * se$ ,  $[-1.780791 \pm 2 * 0.659993 = (-3.100777, -0.460805)]$ .

Lastly, back-transformation to the probability scale gives approximate confidence limits for the probability of a fire at this location of  $(e^{-3.100777} / (1 + e^{-3.100777}), e^{-0.460805} / (1 + e^{-0.460805})) = (0.04307521, 0.3867949)$ .

As a result, we can be 95% certain that the average probability of a human-caused fire at an elevation of 1,453 and a road value of 4,583 meters for the Wellsville data set is between 4% and 39%.

The result of this statistical procedure performed on all four data sets was 12 files: Wellsville lightning and human and Bear River lightning and human, each with a lower, predicted (best estimate), and upper limit (Figure 9). The files contain points with an easting, northing, and a fire probability for that location (Appendix E). From these data, point grids were constructed. Finally,



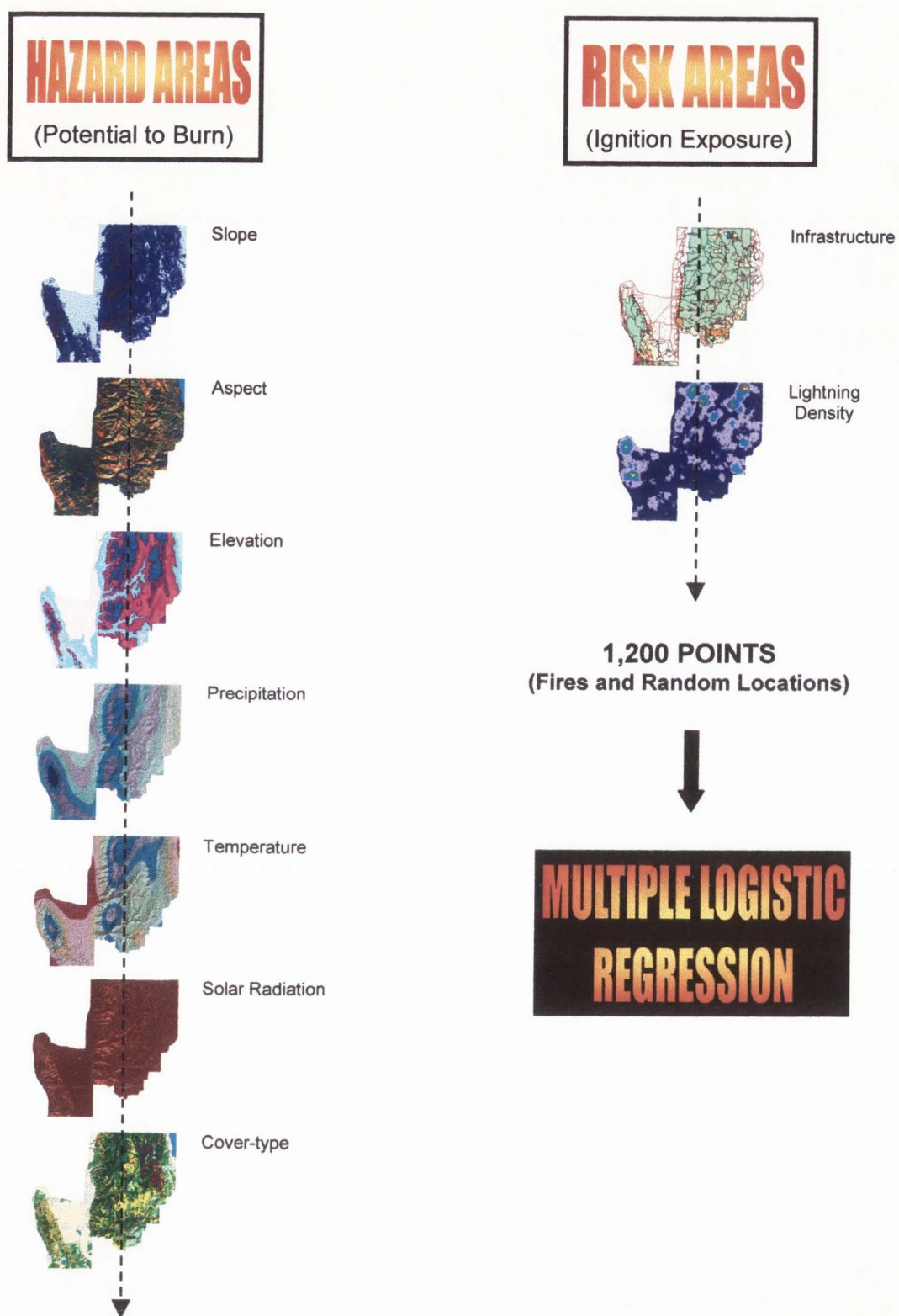


Figure 8. Flow chart of phase 2 fire assessment methodology, chart A.

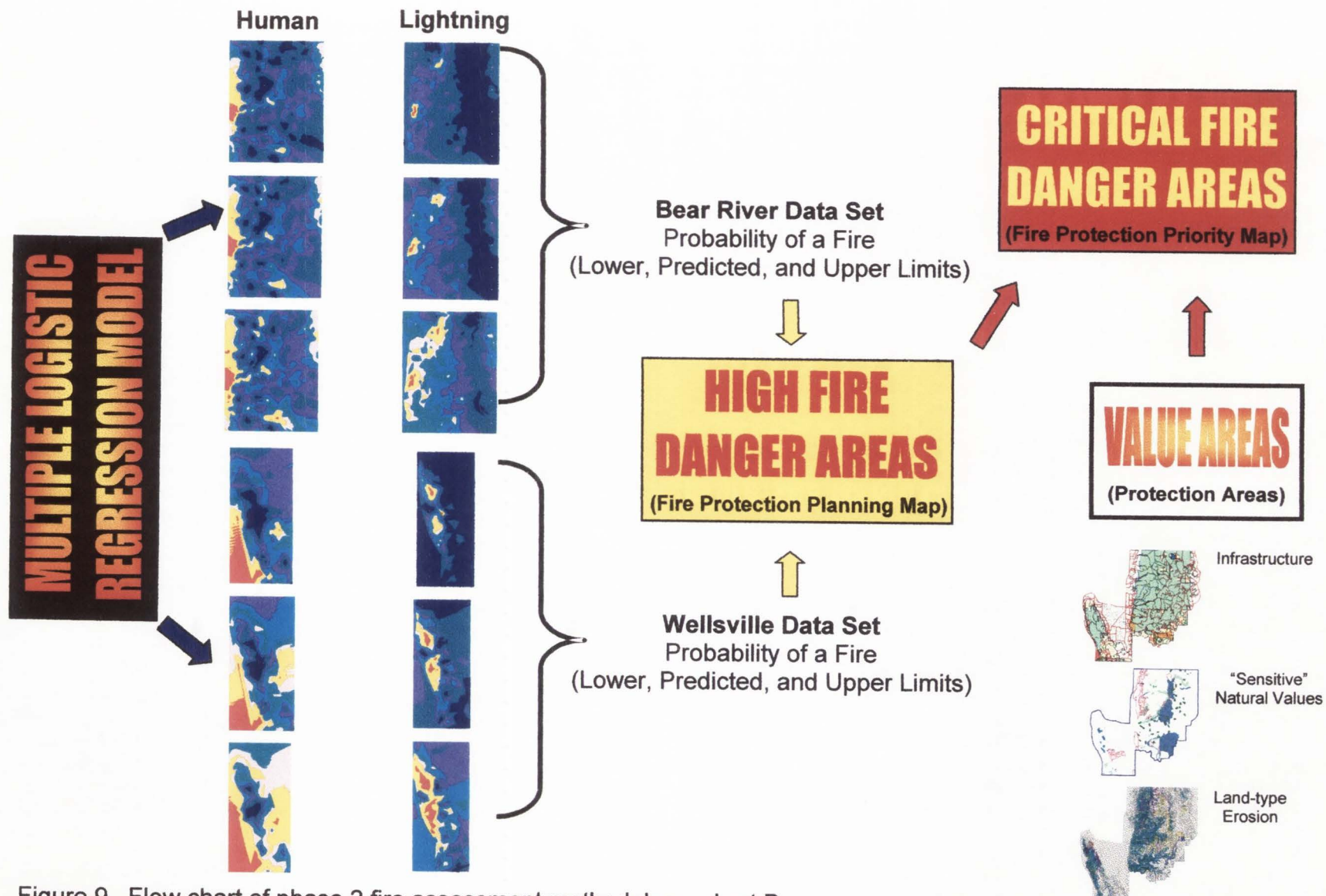
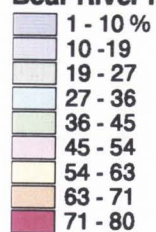
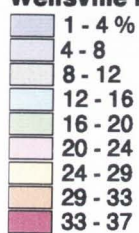


Figure 9. Flow chart of phase 2 fire assessment methodology, chart B.

using the ARC/GRID "kriging" command (spherical option), points were interpolated, generating grids containing the final fire probability areas (Figures 10-15).



**Bear River Human Lower Limit****Wellsville Human Lower Limit**

Scale 1:300,000

0 4 8 12 16 km

Figure 10. Human-caused fire probability, lower limit.



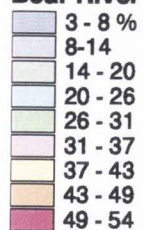
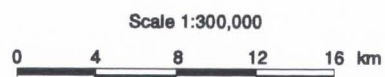
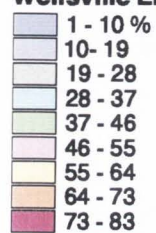
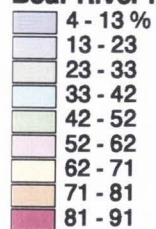
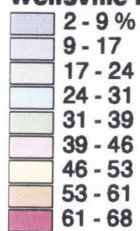
**Bear River Lightning Lower Limit****Wellsville Lightning Lower Limit**

Figure 11. Lightning-caused fire probability, lower limit.

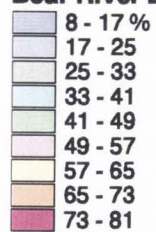
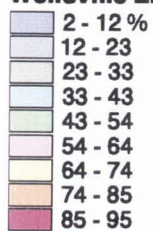
**Bear River Human Predicted****Wellsville Human Predicted**

Scale 1:300,000

0 4 8 12 16 km

Figure 12. Human-caused fire probability, predicted limit.

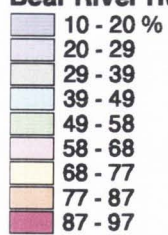
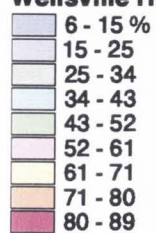


**Bear River Lightning Predicted****Wellsville Lightning Predicted**

Scale 1:300,000



Figure 13. Lightning-caused fire probability, predicted limit.

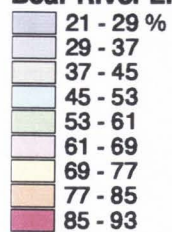
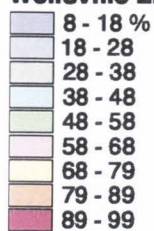
**Bear River Human Upper Limit****Wellsville Human Upper Limit**

Scale 1:300,000

0 4 8 12 16 km

Figure 14. Human-caused fire probability, upper limit.



**Bear River Lightning Upper Limit****Wellsville Lightning Upper Limit**

Scale 1:300,000

0 4 8 12 16 km

Figure 15. Lightning-caused fire probability, upper limit.

## DISCUSSION

This assessment method provides land managers with important information about the likelihood of a wildland fire. Phase 1 is effective for broad-area-based management both to locate high danger areas and to identify areas in need of a phase 2 assessment. Phase 2, with a lower, predicted, and upper limit (the confidence interval), provides fire managers with a 95% certainty that the predicted value is correct.

Although this prediction method allows for a large fire prediction range (e.g., 4-39% for a human-caused fire in the Wellsville data set), managers can depend on the predicted map as the "best guess." The lower and upper limits can be thought of as the "best-" and "worst-case" scenarios, respectively. This is of particular relevance to fire managers where fires are frequently expressed using these terms.

### Predictor Variable Significance

#### **Significant Predictors**

Results from the multiple logistic regression procedure were valuable in identifying which GIS layers (explanatory variables) are effective at predicting fire occurrence. Temperature was the most frequently used predictor, followed by elevation, nearness to roads, precipitation, slope, aspect, and nearness to trails, respectively.

Nearness to roads and trails was used when predicting human-caused fires (Table 1). In the Wellsville lightning data set, the roads variable was also a predictor for lightning-caused fires. At first glance this is surprising, but further study indicates that roads are acting as a surrogate (in place of) elevation, which seems viable when one considers there are no roads in the wilderness area and the roads are located at the lowest elevations.

### **Insignificant Predictors**

Fire managers may look at Table 1 from a fire behavior perspective and question the use of some of the predictor variables. It is worthwhile to remember that what is most meaningful from a fire behavior standpoint (i.e., weather, [relative humidity, wind], fuel moisture content, slope, and vegetation [type and arrangement]), may not necessarily be essential for a fire assessment. This should not come as a surprise when considering that fire assessments are generally based on historical fires rather than actual modeling of fire spread.

Furthermore, many of the fire behavior predictor variables (weather, fuel, and some components of vegetation mapping) are extremely difficult or impossible to accurately represent as a GIS layer. Consequently, this technological limitation and/or the quality of the digital data may falsely limit the variable's significance, rather than the actual factor itself.

This may help to explain why certain variables did not emerge as significant and, therefore, were not used in phase 2. This is probably the case with the cover-type layer, which could have served as a surrogate if needed in a few cases. Since vegetation is a result of many topographic and environmental



variables, it can be a valuable layer. Future assessments may want to concentrate on creating a very accurate vegetation layer, which may result in showing significance for the assessment model.

Another layer that was not used as a predictor was the lightning grid. GAI runs the most exact lightning detection system in the world, yet this study indicates that the data were not significant at the  $\alpha=.05$  level. There are a number of possible explanations. First, the reporting data is only for a 2-year period, while a 10-year period is ideal to evaluate the cyclic pattern of lightning occurrence (Geitz 1997; van Wagtendonk 1997).

Second, there may have been errors in the fire reports. The Bear River lightning predicted map shows that the Logan Canyon area is a high-lightning area. Contrast this to the lightning density map. Often when an ignition device is not discovered a lightning ignition is assumed. This sometimes is valid, but when these fires occur near roads or high population areas, questions are raised. This could well be the case for a number of fires near the mouth of Logan Canyon.

Third, when the lightning density grid was created, it was divided into nine classes. If other combinations of classes had been explored more thoroughly, a more significant one might have been discovered.

Fourth, and perhaps most obviously, to report a lightning fire, it must be detected. Usually lightning fires occur in secluded areas at high elevations and lightning strikes do not always result in an ignition. This is consistent with the findings of van Wagtendonk (1991):

Although most lightning strikes occur at higher elevations, lightning fires are most prevalent at 7,000 feet... above 8,000 feet, lightning



strikes are frequent but fuels are sparse and lightning is usually accompanied by some precipitation. Consequently, few fires occur there. (p. 610)

In this study, the lightning density grid might only act as a surrogate for elevation for both lightning data sets.

Lastly, solar radiation might become more useful if it were constructed daily for the full fire season (May – October) and at shorter time intervals (e.g., every 15 to 30 minutes). This was not examined more closely because of the time restraints and the presence of the precipitation and temperature grids, as well as the other topographic layers, thus possibly making solar radiation a redundant predictor variable. In future assessments, solar radiation may be useful, particularly if precipitation and temperature grids are not available. As the accuracy and effectiveness of remote sensing and GIS technology increase, present predictor variables will be improved and new ones will be used to predict fire occurrence more effectively.

### Critical Fire Danger Areas

From the predicted fire probability grids (Figures 12 and 13), areas of critical fire danger were identified. These areas are those that are most likely to experience a fire within or near protection areas (human or “sensitive” natural values). To do this, portions of the infrastructure theme (see Figure 27) and the “sensitive” natural-value theme (see Figure 33) are overlaid. Figures 16-17 display 3-D, southwest perspectives of the Bear River and Wellsville predicted

data sets overlaid with major roads. Figure 18 exhibits a 3-D westerly and easterly view of classical interface areas from the Bear River human predicted data set. Figure 19 shows other critical fire danger areas, where habitat for endangered plant and bird species, the Maguire Primrose (*Primula maguirei*) and the Northern Goshawk (*Accipiter gentilis*), are in close proximity to high fire danger areas.

Likewise, at the discretion of fire managers, similar overlay operations can be done throughout the study addressing a variety of concerns (e.g., erosion, scenic values, old growth areas, etc.). These areas can then be prioritized and targeted for presuppression mitigation efforts.

### Applications

There are many benefits and applications of a wildland fire assessment. Although the maximum benefits are realized when both phases of assessment are used, many of the following applications are applicable for phase 1 alone. Most important, because GIS is a commonly used modeling and planning technology, it lends itself well to the sharing and updating of information between different agencies and organizations (USDA 1996).

The most obvious and possibly the most significant use of this study is as a model for future assessments. As the dollar cost and loss of life and property increase from fires, particularly in the wildland-urban interface, local, state, and federal officials as well as the commercial sector (i.e., insurance and risk



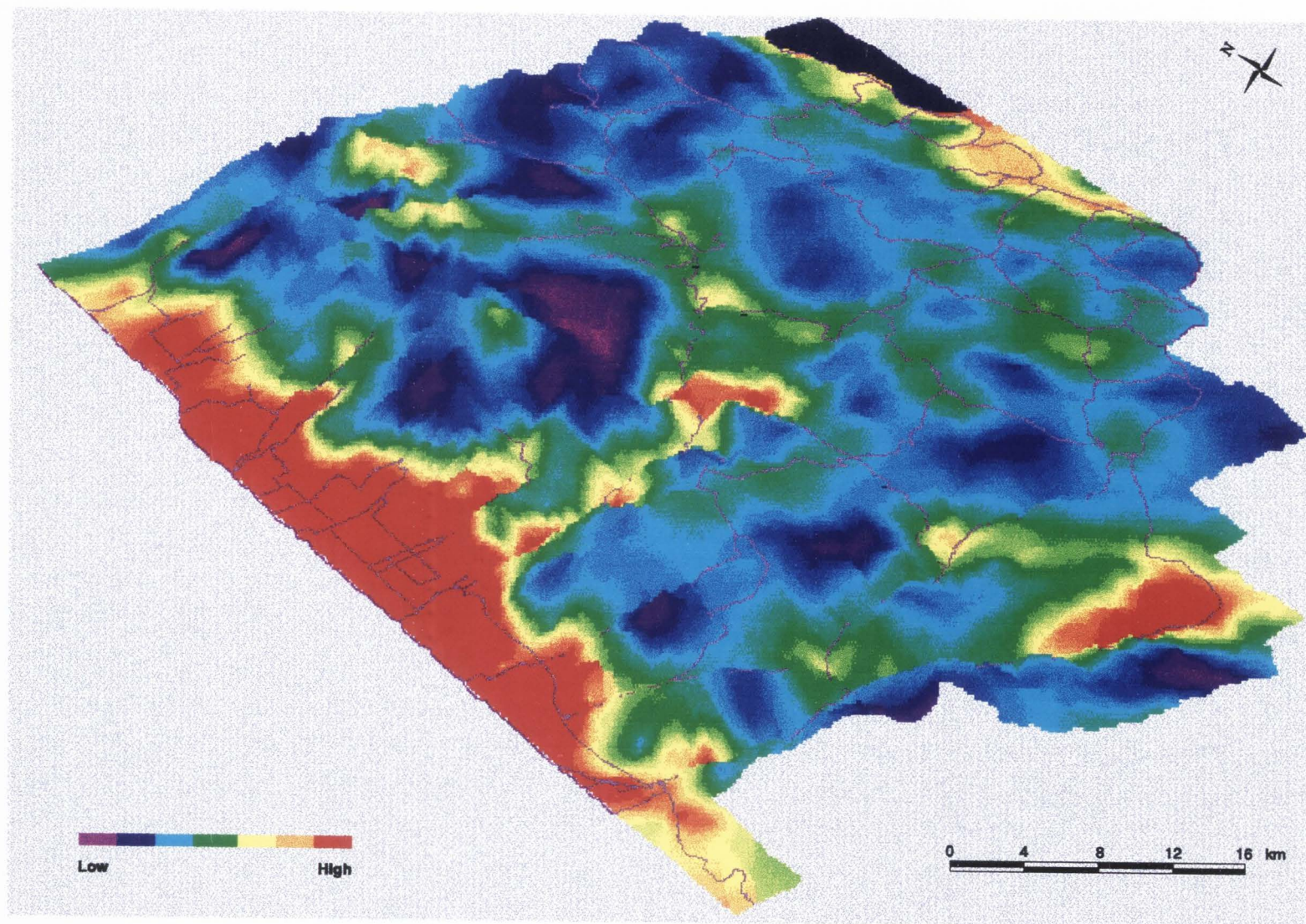


Figure 16. 3-D, southwest perspective of Bear River human fire probability, predicted limit.



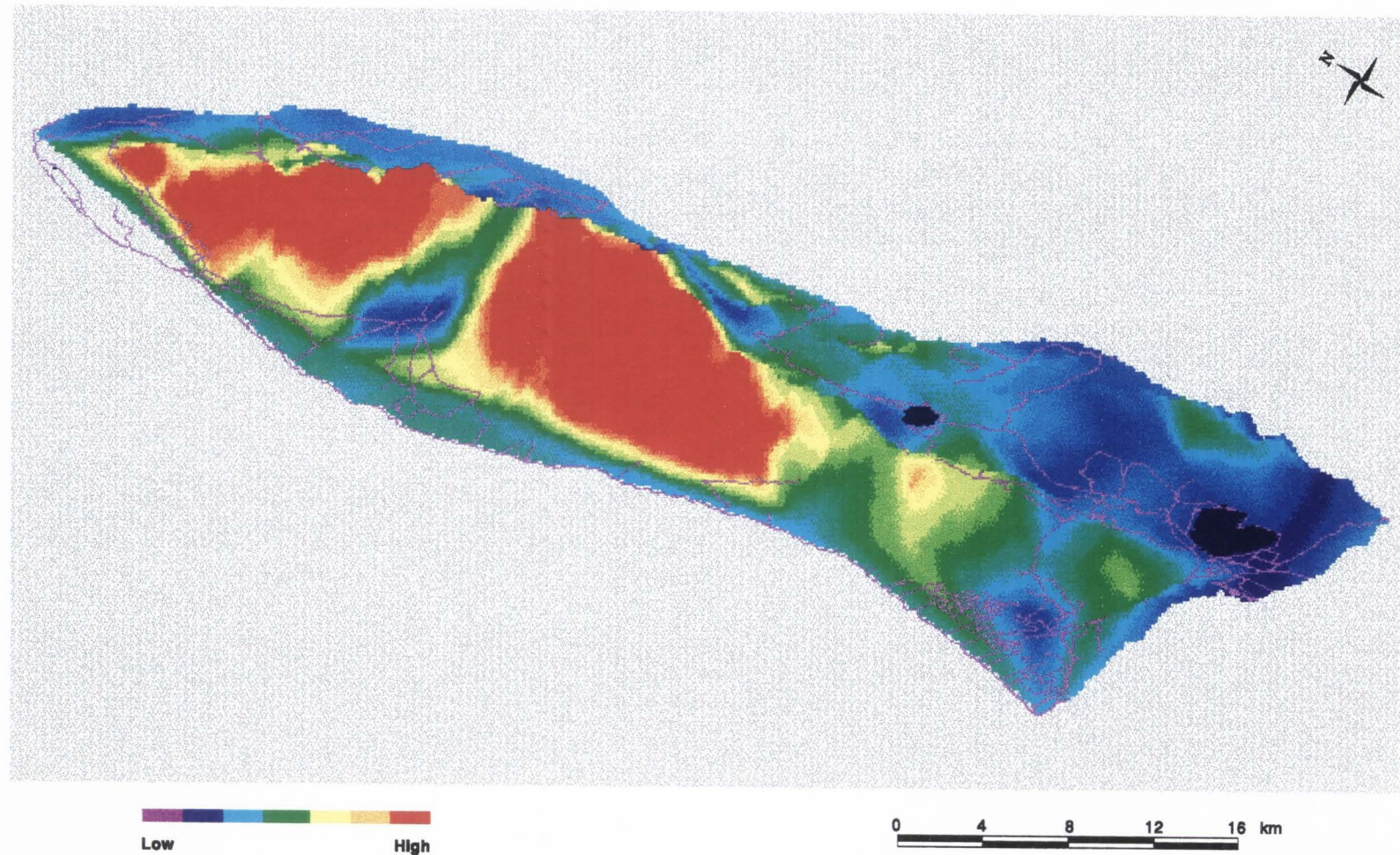


Figure 17. 3-D, southwest perspective of Wellsville lightning fire probability, predicted limit.



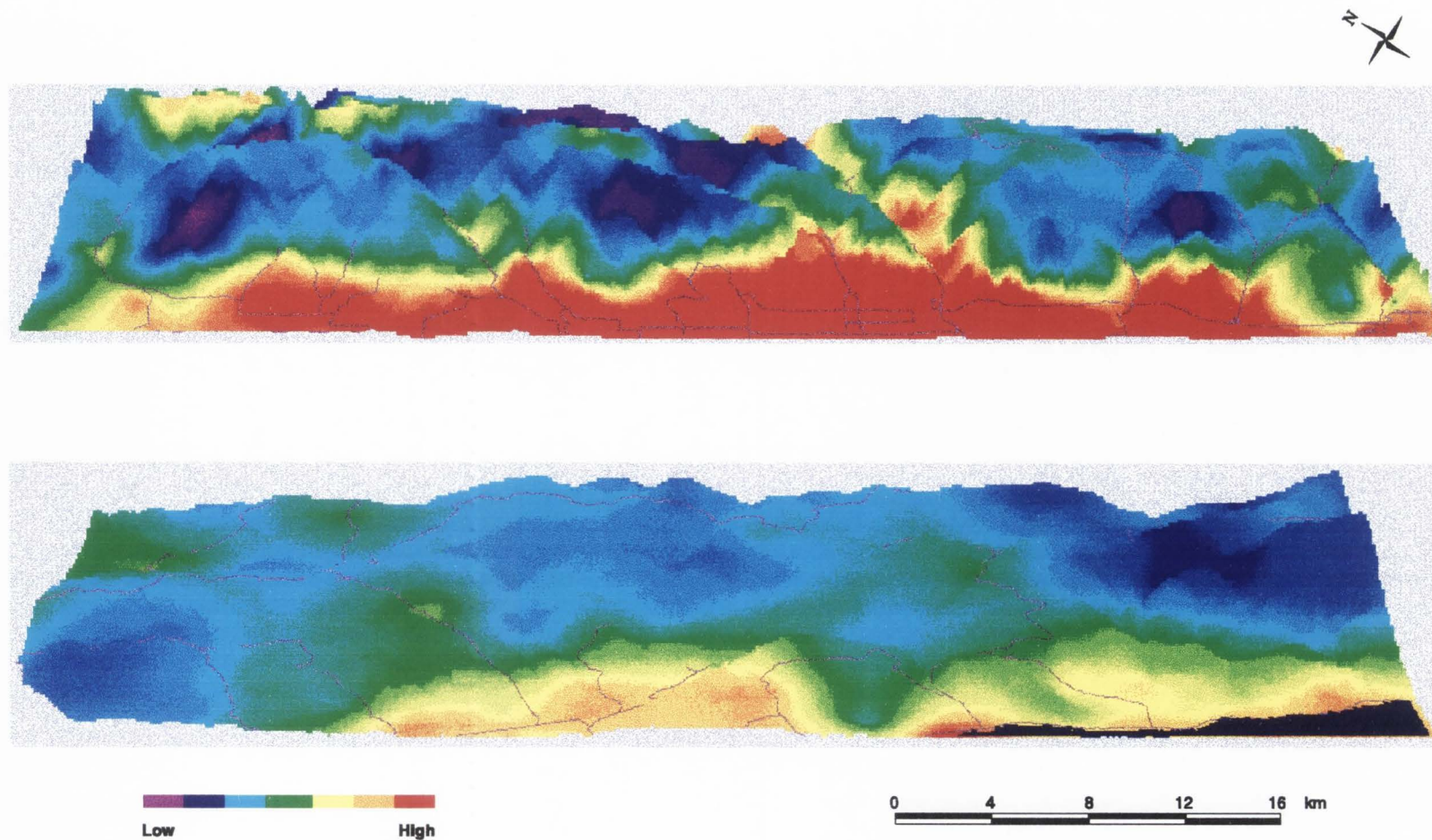


Figure 18. 3-D perspective of Bear River human fire probability, predicted limit, viewed from the Logan (top) and Bear Lake (bottom) fronts.



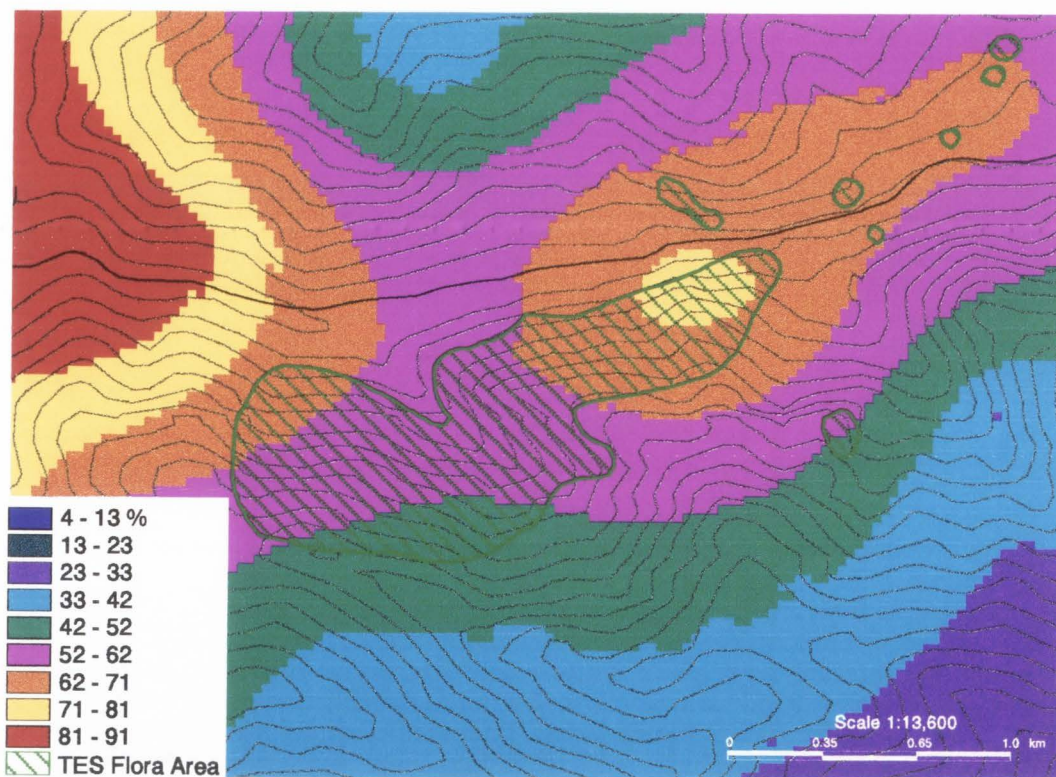
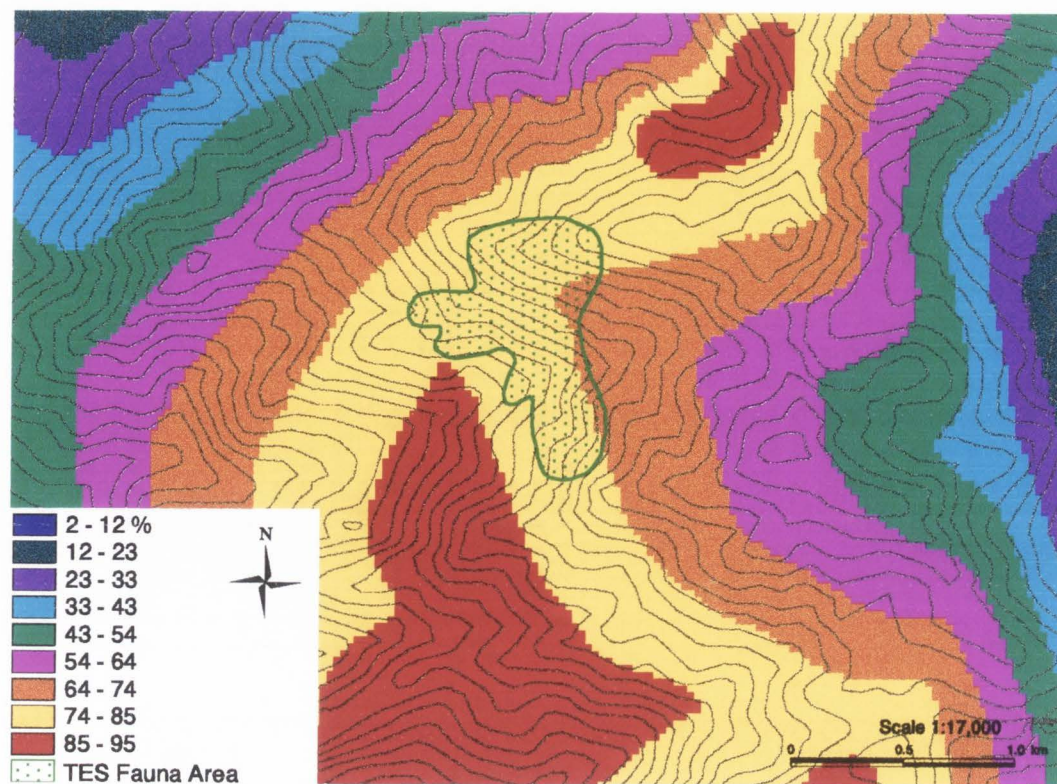


Figure 19. Wellsville lightning predicted (top) and Bear River human predicted (bottom); TES species in high fire danger areas.

assessment companies) will conduct similar studies. Quite possibly, they will seek out those assessments previously conducted, and use them as a guide.

Another valuable application to the study is the newly created assessment database, which can be downloaded to local, state, and federal officials' systems. This allows complete access to the data, thus affording managers potentially limitless applications. Furthermore, not only can the database be used to support fire-related projects, but other disciplines can also benefit, such as recreation, range, wildlife, timber, and visual design.

### **Homeowners**

Homeowners will benefit by increased awareness of the dangers associated with living in the wildland-urban interface. Citizens will be alerted to fire danger areas and can take the necessary precautions. Booklets containing GIS maps and other information, including how to create a defensible space through landscape manipulation, the use of proper building materials, and fire-resistant plant species, can be published and distributed.

### **Local Officials**

A variety of city and county officials can benefit from a fire assessment. Local officials will be able to use the newly created GIS spatial and tabular data for planning and zoning. For example, a county or city fire chief can use the GIS data for fire ordinance development, planning and prepositioning of resources, and fostering homeowner education. Assessment recommendations are also



useful to county and city planners and zoning commissioners, providing an objective study for fire protection measures in the wildland-urban interface.

### **State and Federal Officials**

Using the fire probability maps generated from the assessment, fire specialists can identify areas of greatest potential for wildfire. These high fire danger areas can then be overlaid with the "sensitive" natural-value layer and the infrastructure theme to identify critical fire danger areas. These critical fire danger areas can then be prioritized and targeted by managers for presuppression mitigation efforts, such as hazardous fuels reduction (mechanical and natural), constructing fuel breaks (e.g., greenbelts, parkways), defensible space projects, and so on. Hazard-fuels reduction projects could include prescribed natural fire plans, manager-ignited prescribed fires, particularly in interface areas, and mechanical alteration means (e.g., harvesting of tree species, anchor chaining).

Likewise, land managers will be able use the GIS products to map, monitor, and analyze fires both for suppression and prescription. Aided by a fire growth simulator called FARSITE, managers will be able to spatially predict fire spread, intensity, and behavior and perform more accurate escape fire situation analyses, and evaluate areas for prescribed fires. By using a fire barrier coverage (Figure 20), natural and human-made barriers can be overlaid with protection areas and the fire probability grids to assess fire danger and to aid with suppression tactics.

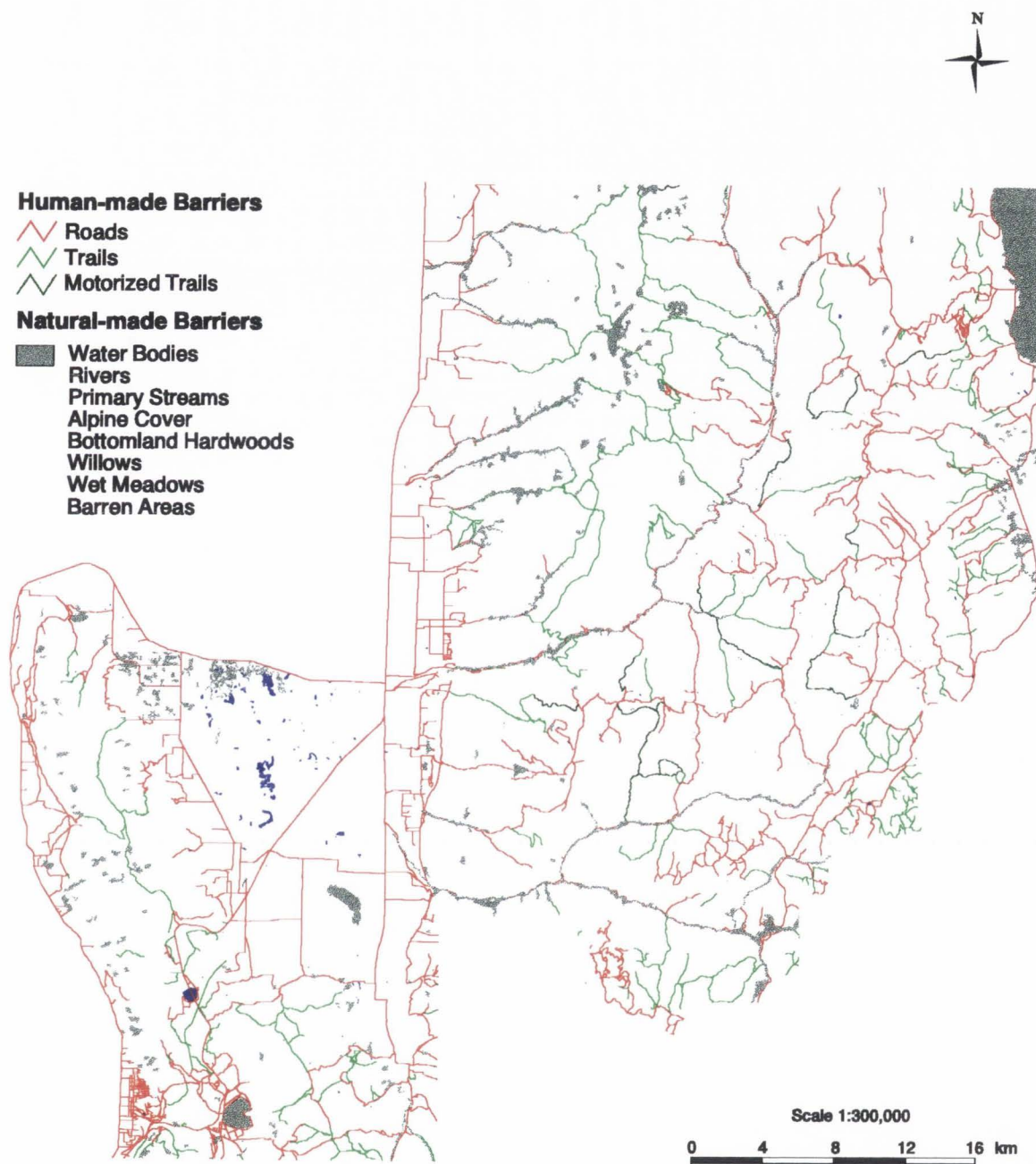


Figure 20. Natural and human-made fire barrier theme.

## FARSITE

With a little extra effort, GIS layers developed for the assessment can be manipulated and exported to create most of the required raster GIS data themes for FARSITE (fire area simulator) (Finney 1996). Aided by this fire growth simulator, fire managers will be able to predict fire behavior and spread in both space and time. This can become extremely useful for both the planning and operational phases of prescribed natural fires and manager-ignited prescribed fires (Figures 21 and 22). In addition, FARSITE allows the user to model fire behavior based in response to a variety of suppression tactics such as hand and dozer (i.e., bulldozer) lines and air operations.

## Global Positioning System (GPS)

GIS layers used for a fire assessment can serve as the base layers for a variety of GPS fire applications. First, a GPS can be used by fire crews (hand, engine, and aerial) to locate, record, and report fire locations. Moreover, characteristics such as fire size, cause, vegetation, slope, and aspect can be collected and downloaded to a computer. Fire locations as well as attribute data become very useful when creating a fire history, conducting historical analyses, or performing a fire assessment.

In addition, on larger fires a GPS can be used by foot, vehicle, or rotor- or fixed-wing aircraft to map a fire perimeter, thus creating fire growth maps as well as a final extant map (Figures 21 and 23). Also it can map areas of importance, such as a helispot, spike camp, or a protection area (e.g., repeater, summer home, etc.).





Figure 21. Helitorch firing pattern for the Red Banks prescribed fire.





Figure 22. FARSITE simulation from helitorch firing pattern for the Red Banks prescribed fire. Final fire perimeter is displayed in blue.

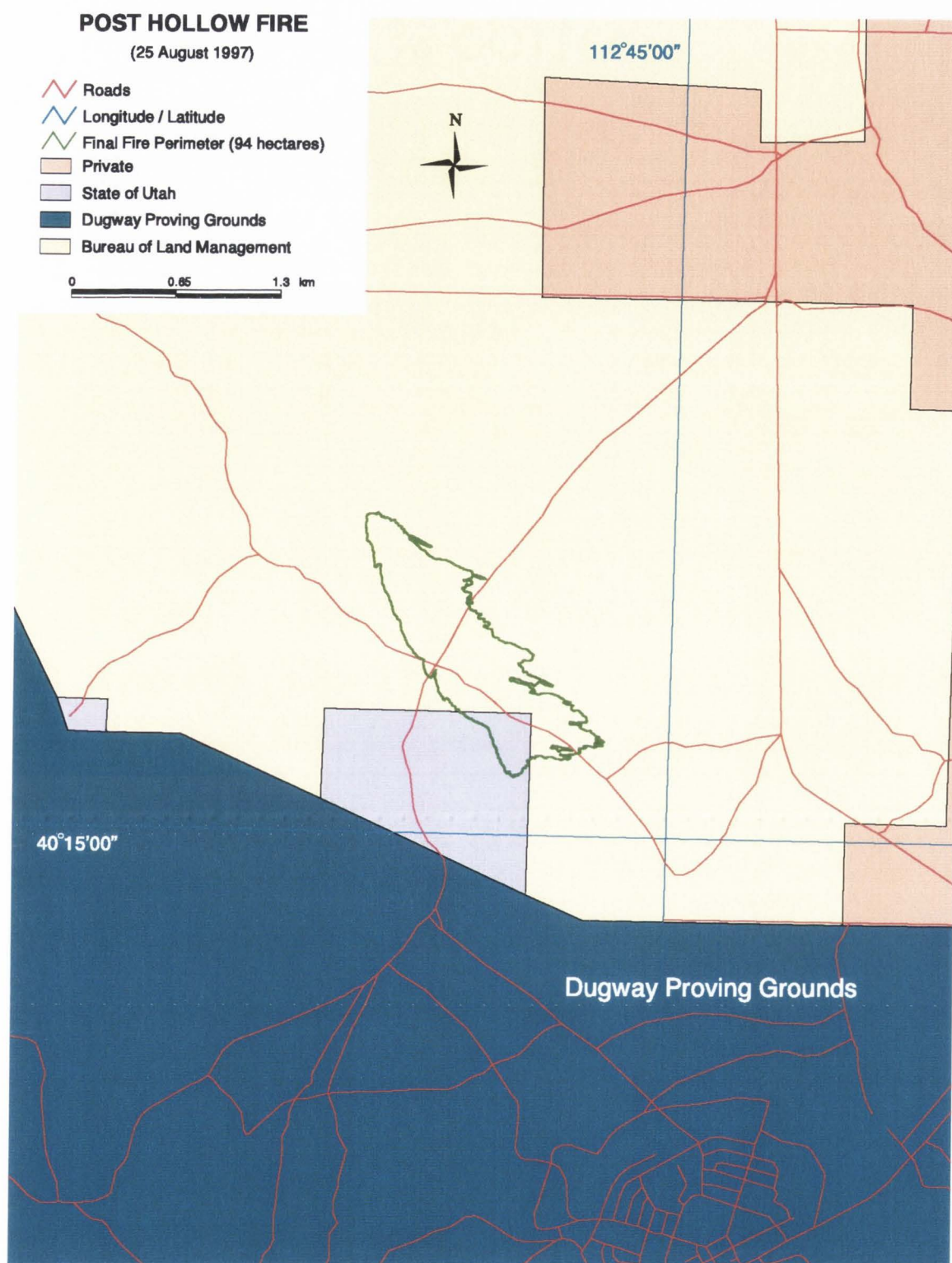


Figure 23. Post Hollow fire, Dugway, Utah.



Not only can a GPS be useful in locating a fire, but it can also be used to navigate. Some possible navigation applications include helping suppression forces to locate a fire based on coordinates (i.e., easting and northing), returning to an old fire in a remote area, and navigating to a particular area on a fire, such as a drop point where food or equipment is deposited.

## CONCLUSION

As the frequency, complexity, and severity of wildland fires increase, it becomes critical for fire managers to have accurate and effective methods to cope with this escalating problem (Davis 1989). Because GIS technology has the capability to organize large amounts of data, perform complex analyses, and display the results spatially, it is an ideal tool for fire specialists. Furthermore, since GIS is frequently used in land management, it is a common thread of communication, thus facilitating the sharing and updating of geographic information between resource professionals of different agencies and organizations. This is of particular interest at a time of agency down-scaling, partnership-building, and broad-area-based management.

This thesis presented two phases of assessment: a preliminary analysis designed for planning use at the landscape level (phase 1), and a detailed analysis for site-specific use (phase 2). Results of the phase 1 assessment were useful in delineating areas of high fire occurrence and suggesting to managers where a phase 2 assessment is needed.

By using environmental, human, and topographic information and multiple logistic regression, probability maps of wildland fire occurrence were created (phase 2). Significant predictor variables used in the creation of the fire probability grids include temperature, elevation, nearness to roads and trails, precipitation, slope, and aspect. Other explanatory variables analyzed but not found significant at the  $\alpha=.05$  level were cover-type, lightning density, solar radiation, ownership, and date of fire.

The assessment methodology presented in this thesis, combined with the expertise of fire specialists, offers an improved and cost-effective assessment technique in wildland fire management, benefiting local, state, and federal governments as well as the people they serve. When it is implemented properly, firefighting expenditures will decrease and tragic loss of life, property, and natural resources will be reduced. Indeed, this project may also serve as a foundation for other assessments in other areas and as a prototype for the national hazard and risk assessment model as proposed by the Western Governors' Association.

Having said this, it is important to remember this statement by James Davis (1990), research forester, USDA Forest Service:

There is no single solution to the wildland-urban interface fire problem. Because so many hazards, risks, and related factors are involved, a combination of remedies must be used to achieve any reasonable degree of fire safety for structures in or near wildland areas. (p. 31)



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## APPENDICES



Appendix A  
GIS Data Layers

**Elevation in Meters**

|             |
|-------------|
| 1289 - 1523 |
| 1524 - 1675 |
| 1676 - 1828 |
| 1829 - 1980 |
| 1981 - 2133 |
| 2134 - 2285 |
| 2286 - 2437 |
| 2437 - 2590 |
| 2591 - 2742 |
| 2743 - 2895 |
| 2896 - 3030 |

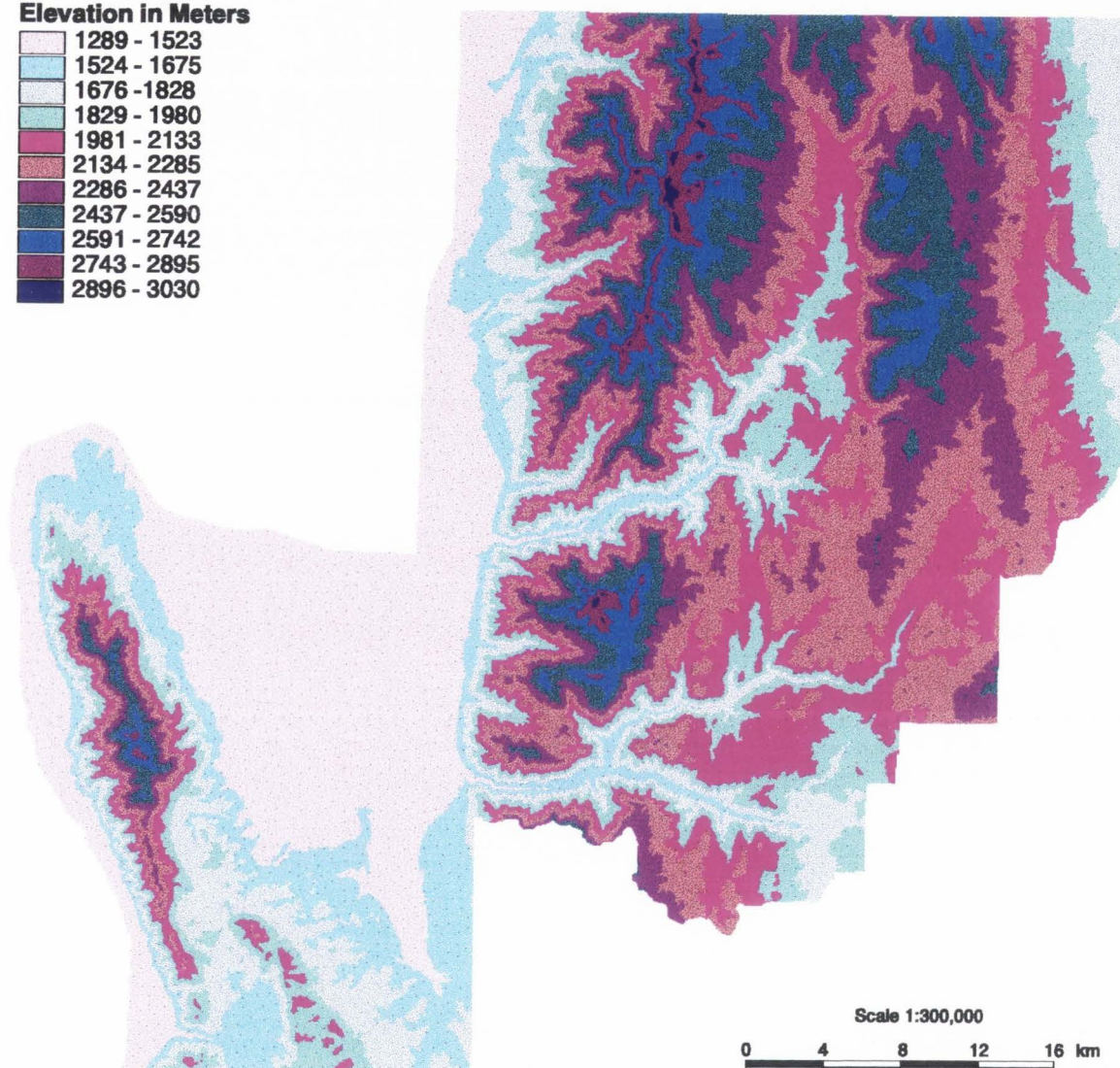


Figure 24. Elevation classification.

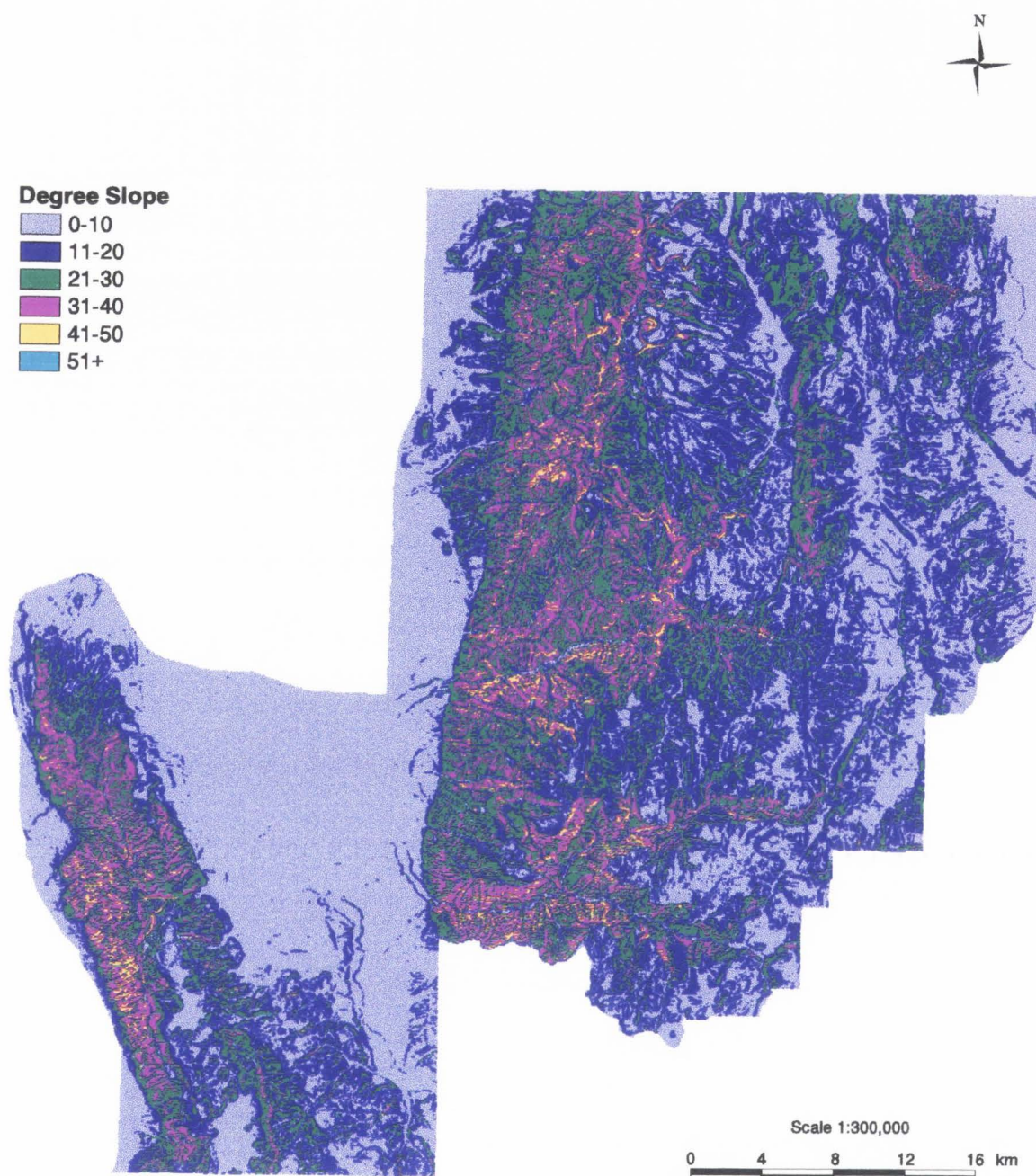


Figure 25. Slope classification.





**Aspect Expressed in  
Degrees from 0 to 360**

|      |                 |
|------|-----------------|
| Flat | (-1)            |
| NE   | (22.5 - 67.5)   |
| E    | (67.5 - 112.5)  |
| SE   | (112.5 - 157.5) |
| S    | (157.5 - 202.5) |
| SW   | (202.5 - 247.5) |
| W    | (247.5 - 292.5) |
| NW   | (292.5 - 337.5) |
| N    | (337.5 - 22.5)  |

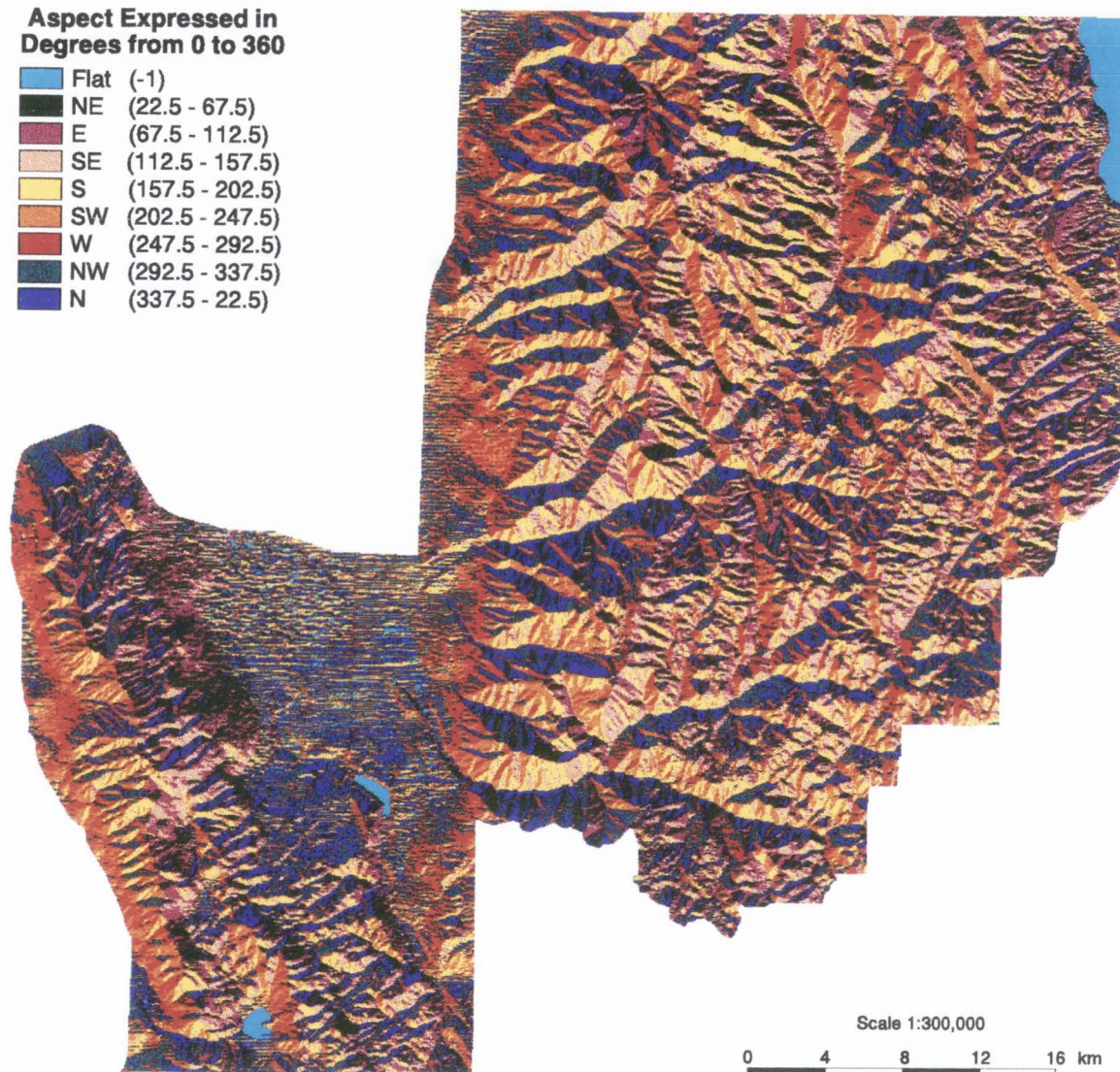
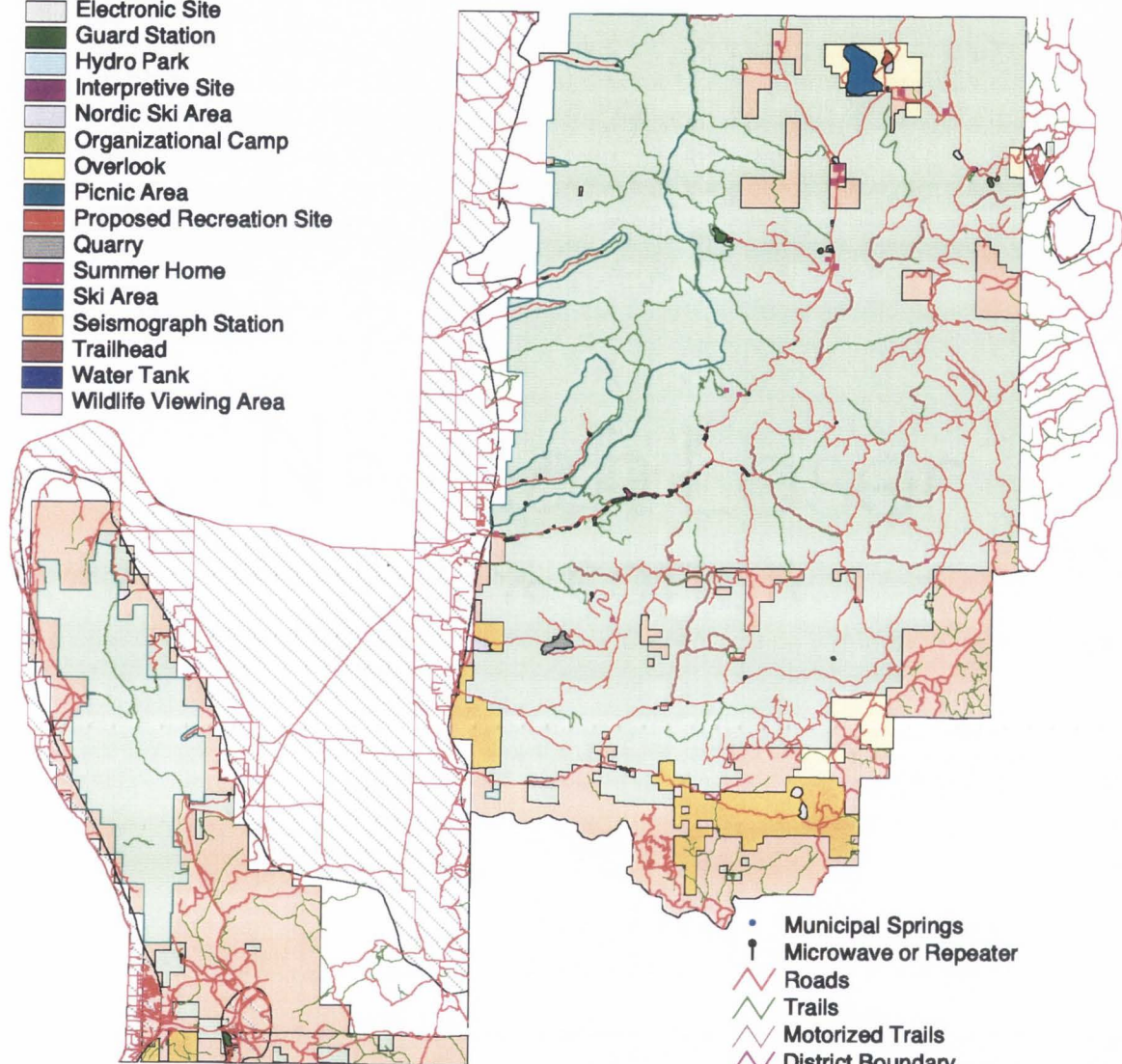


Figure 26. Aspect classification.

**Special Use Areas**

- Administrative Area
- Campground
- Electronic Site
- Guard Station
- Hydro Park
- Interpretive Site
- Nordic Ski Area
- Organizational Camp
- Overlook
- Picnic Area
- Proposed Recreation Site
- Quarry
- Summer Home
- Ski Area
- Seismograph Station
- Trailhead
- Water Tank
- Wildlife Viewing Area



Scale 1:300,000

0 4 8 12 16 km

- Municipal Springs
- Microwave or Repeater
- Roads
- Trails
- Motorized Trails
- District Boundary
- Wildland-Urban Development
- Wilderness Area

**Ownership**

- Division of Wildlife Resources
- Private, within forest boundary
- Private, outside of forest boundary
- State Lands and Forestry
- Wasatch-Cache National Forest

Figure 27. Infrastructure theme.



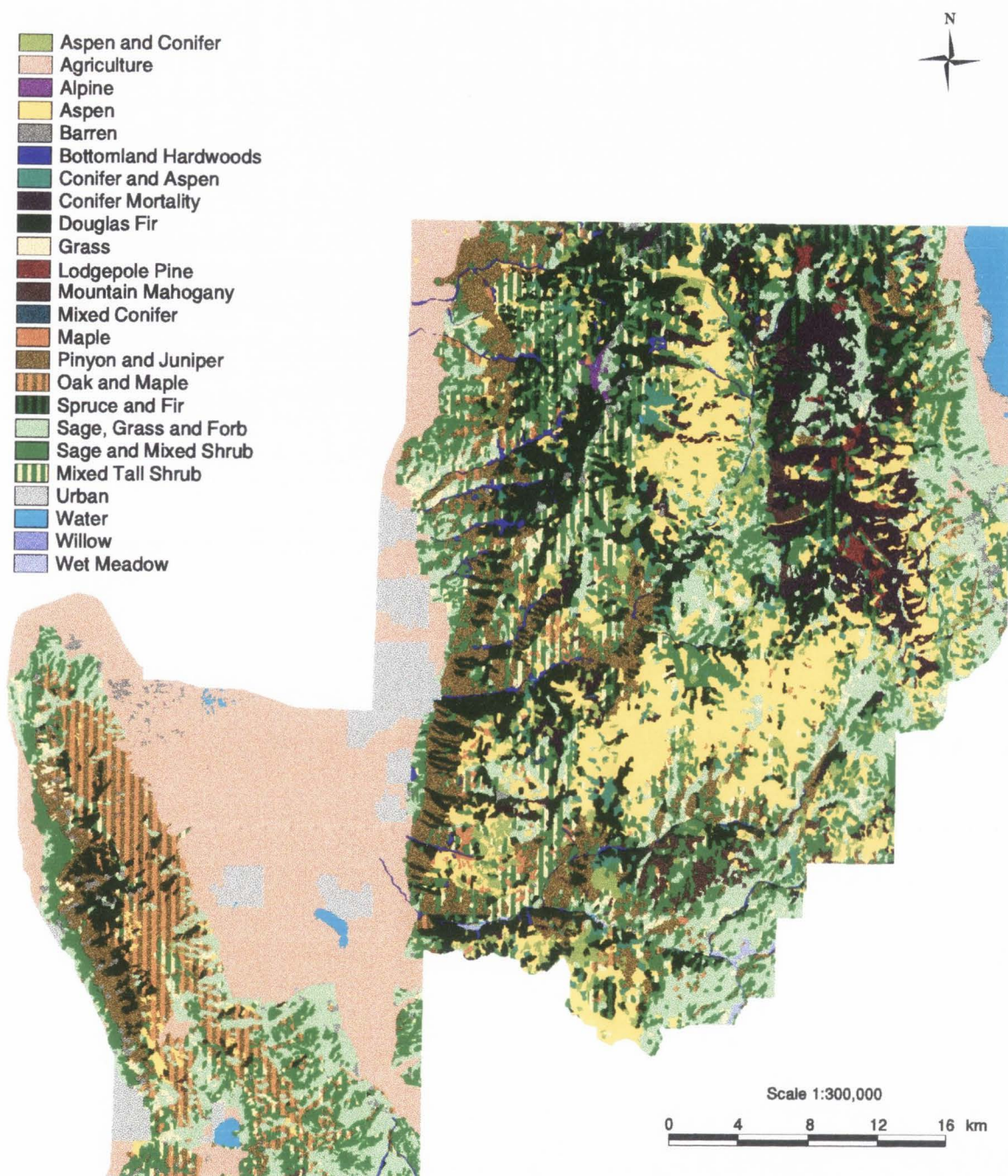


Figure 28. Cover-type classification.



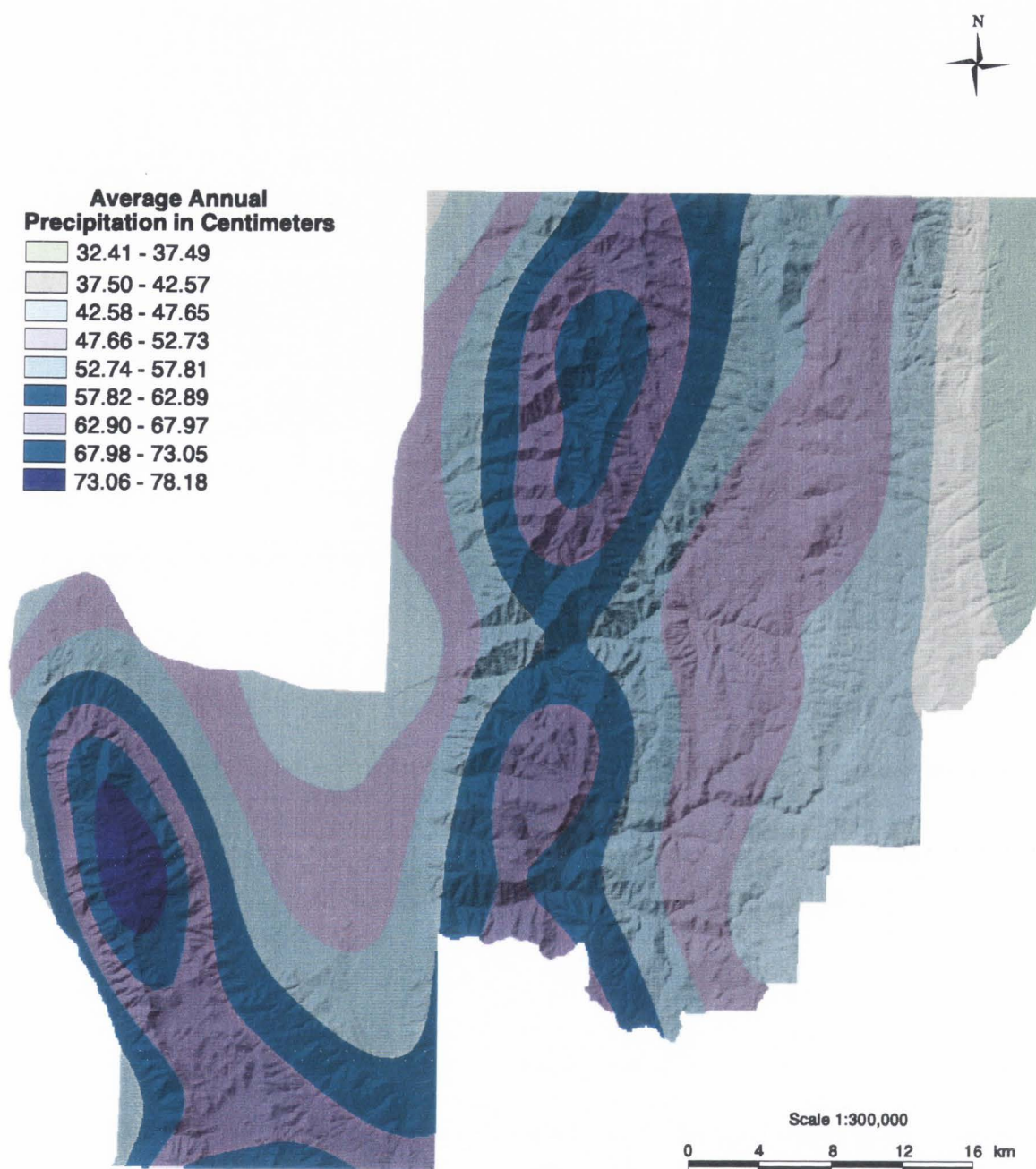


Figure 29. Precipitation classification.

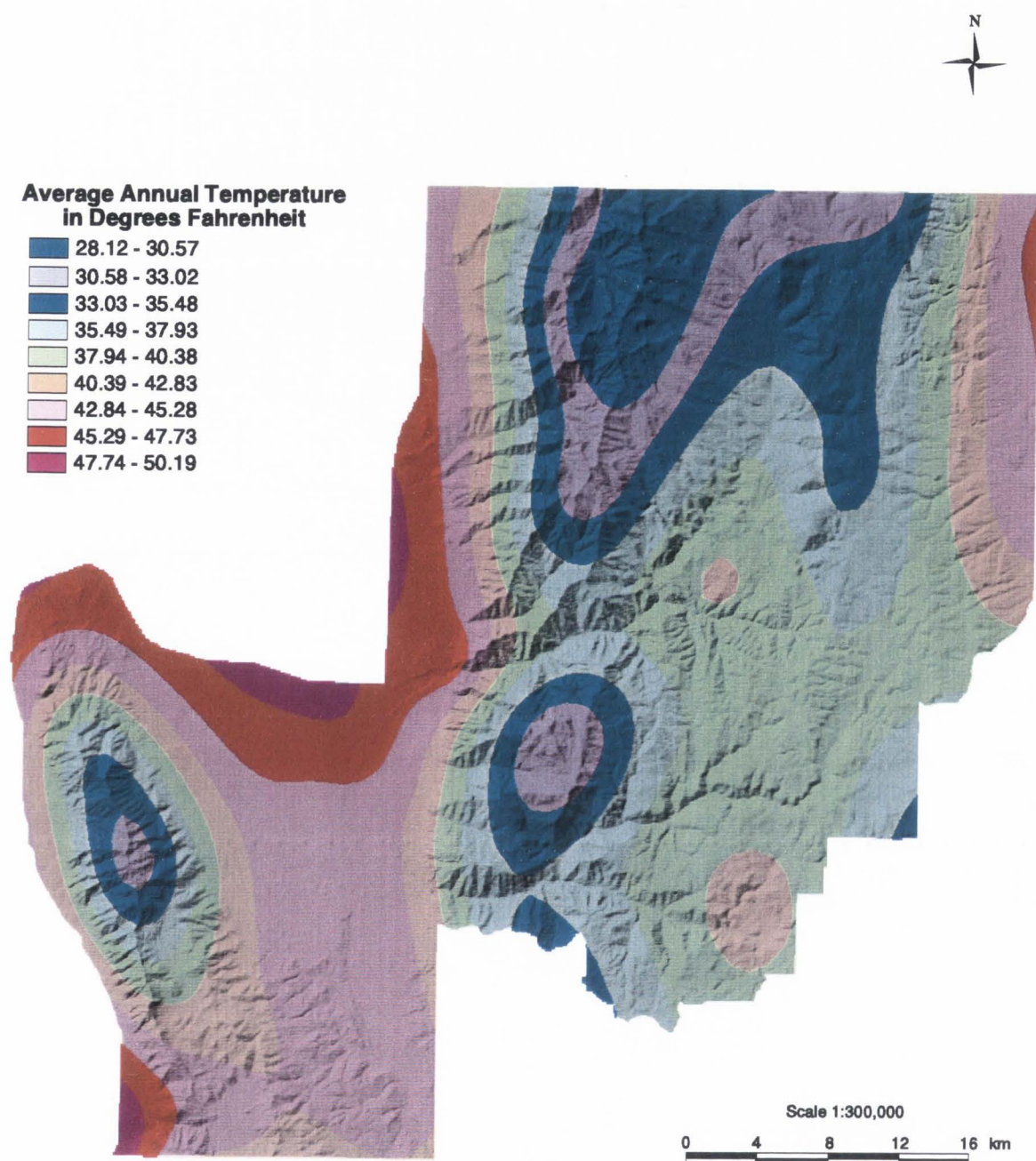


Figure 30. Temperature classification.



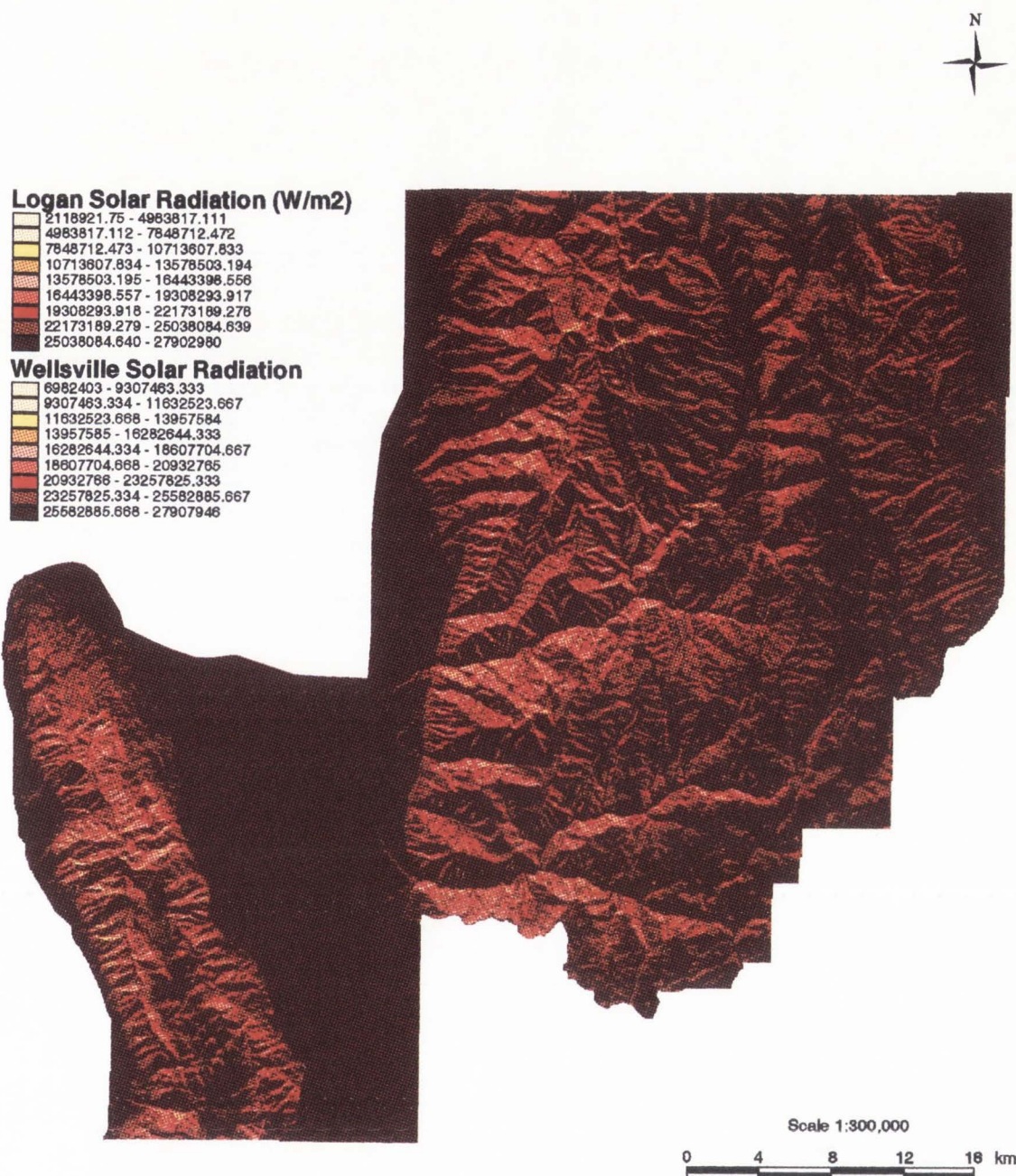


Figure 31. Solar radiation classification.



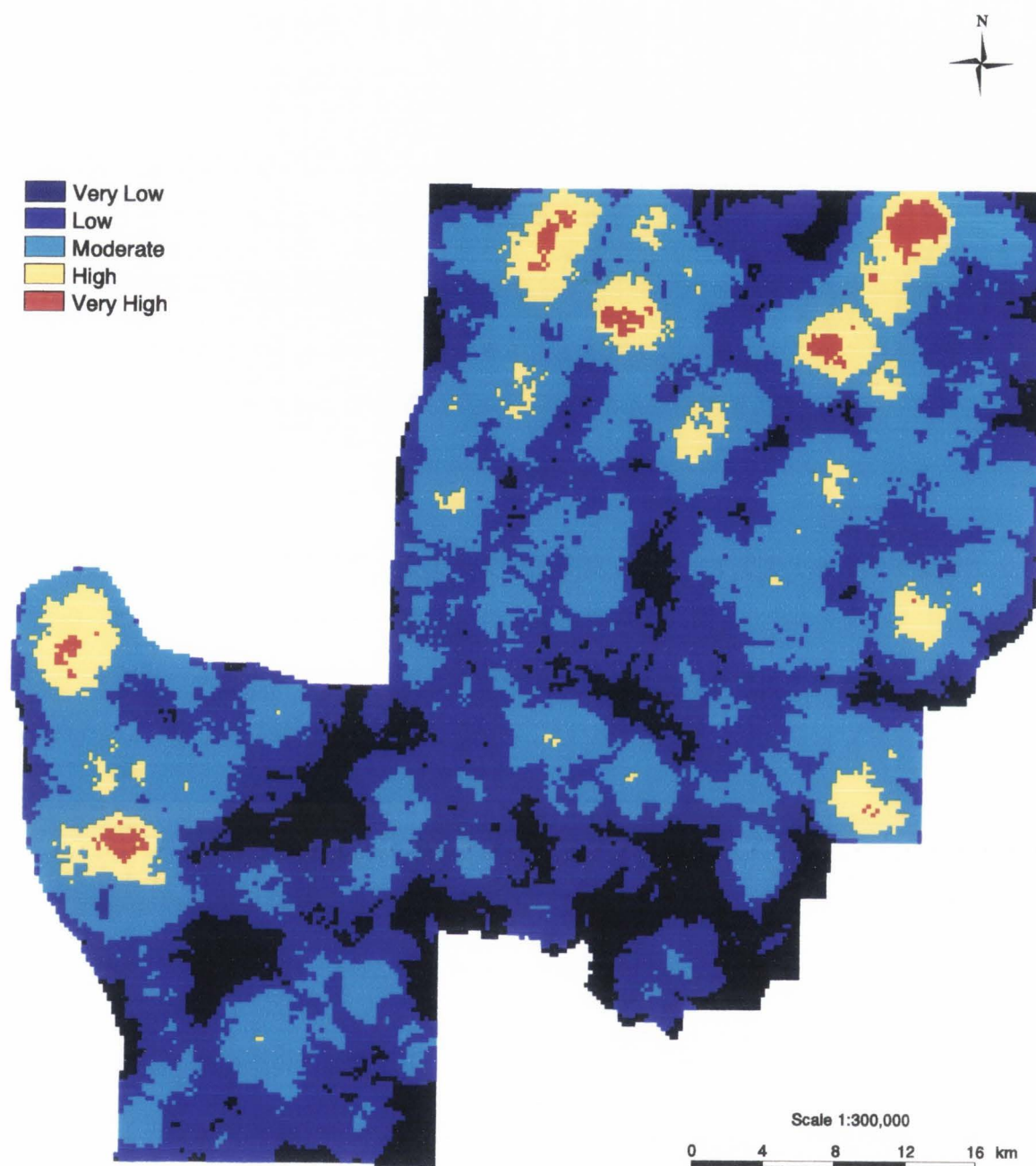


Figure 32. Lightning density map.

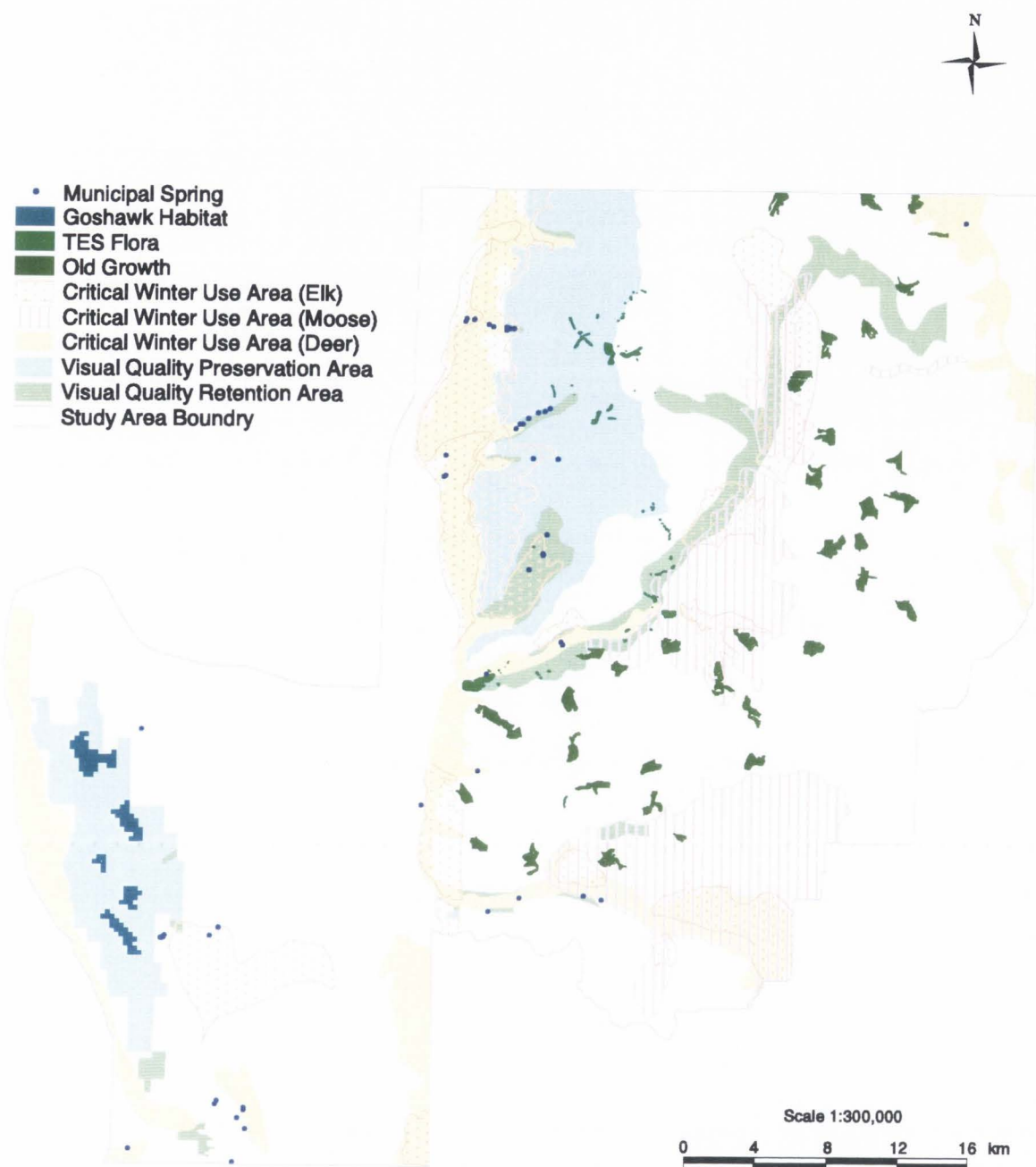


Figure 33. "Sensitive" natural value theme.



### Land-types

|  |      |  |      |
|--|------|--|------|
|  | as   |  | mds  |
|  | baf  |  | prg  |
|  | blg2 |  | psg2 |
|  | bv1  |  | rdg2 |
|  | bv2  |  | sl1  |
|  | has  |  | sl3  |
|  | hsg2 |  | sl4  |
|  | kl2  |  | stg  |
|  | mag  |  |      |

### Degree Slope

|  |       |
|--|-------|
|  | 0-10  |
|  | 11-20 |
|  | 21-30 |
|  | 31-40 |
|  | 41-50 |
|  | 51+   |

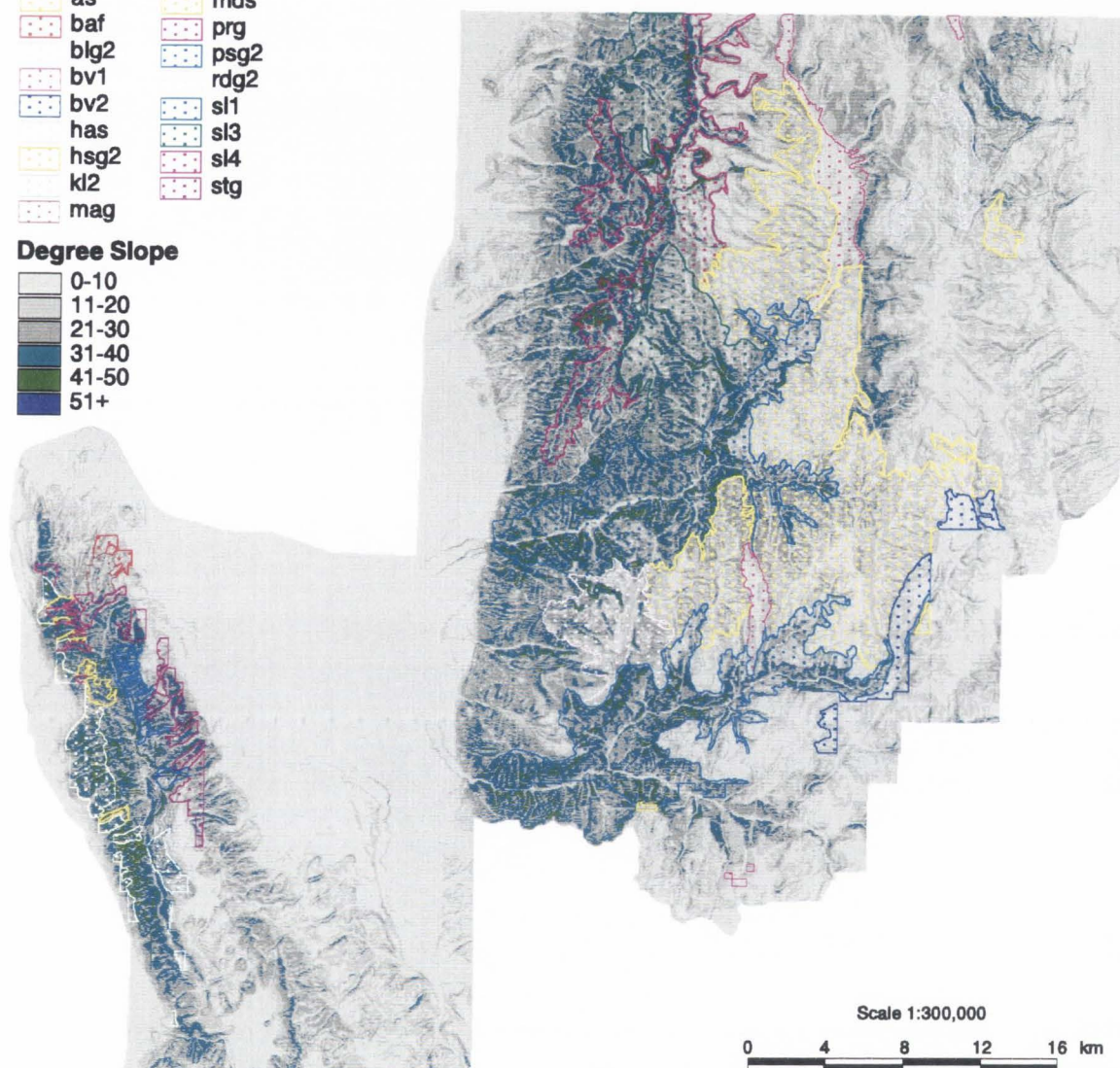


Figure 34. Land-type erosion layer with degree slope.



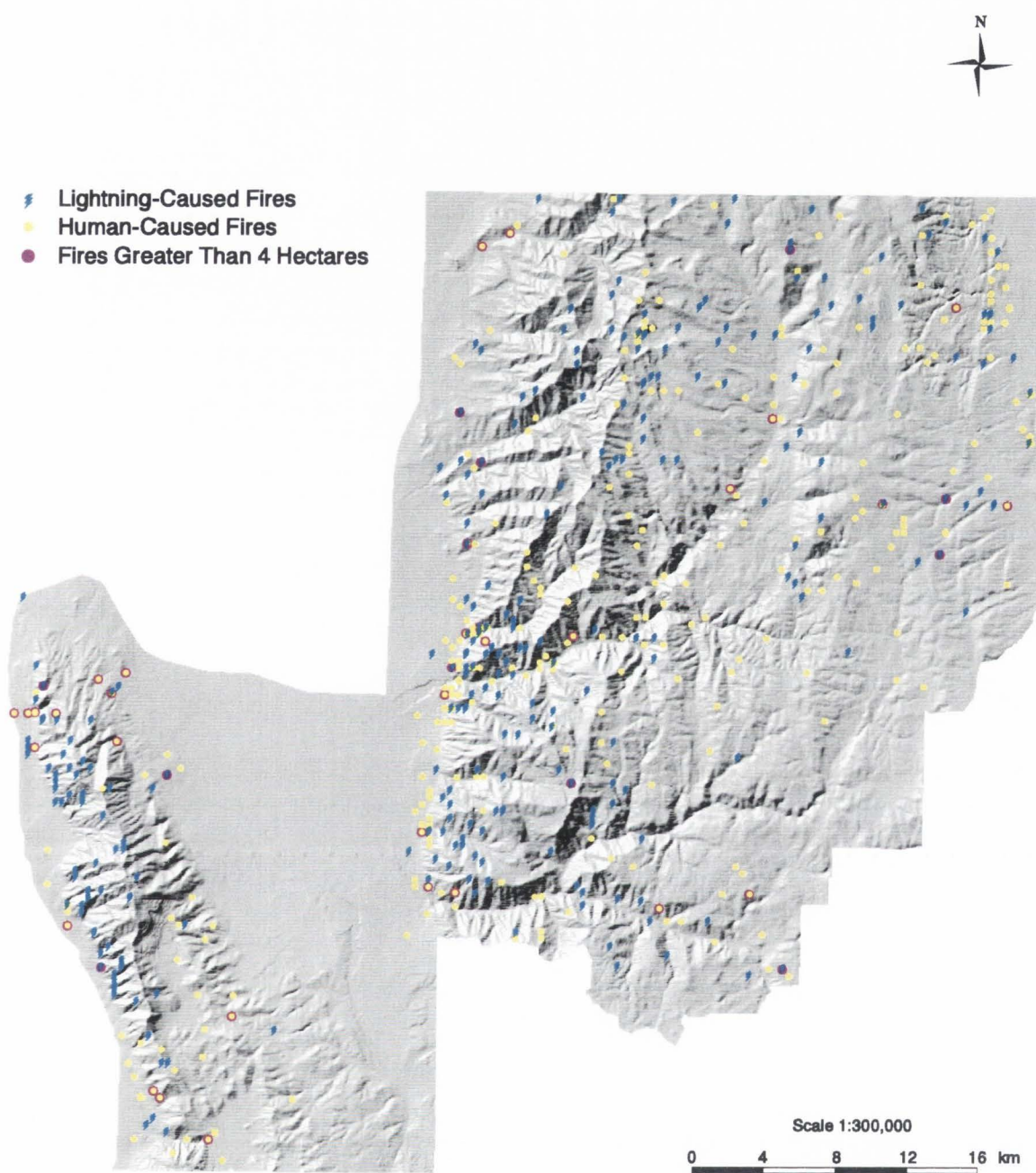


Figure 35. Fire history layer.

Appendix B  
Fire History Results

Appendix B. Fire History Results. With the exception of location, date, cause, and ownership, fire records did not prove to be as useful as anticipated. Still fire records did provide useful information about historical fire trends.

Table 2. Fire history results (1968-1996, federal, state, county, and private lands).

| Cause            | Forest Service | State, County, & Private | Totals     | Percent |
|------------------|----------------|--------------------------|------------|---------|
| Lightning        | 216            | 62                       | 278        | 46%     |
| Human-caused     | <u>174</u>     | <u>148</u>               | <u>322</u> | 54      |
| <b>Subtotals</b> | 390            | 210                      | 600        |         |

| Human-Caused Fires         | Number of Fires | Percent |
|----------------------------|-----------------|---------|
| Arson                      | 4               | 1%      |
| Campfires                  | 121             | 38      |
| Children Miscellaneous     | 4               | 1       |
| Debris and Field Burning   | 29              | 9       |
| Equipment (including cars) | 37              | 11.5    |
| Firearms                   | 3               | <1      |
| Fireworks                  | 15              | 4.6     |
| Other Incendiary           | 36              | 11      |
| Power Lines                | 15              | 4.6     |
| Railroad                   | 2               | <1      |
| Smoking                    | 44              | 13.7    |
| Unknown                    | <u>12</u>       | 3.7     |
| <b>Total</b>               | 310             |         |

| Acres            | Fires on F.S. Land | Fires on Other | Totals   | Percent |
|------------------|--------------------|----------------|----------|---------|
| 0 - .25          | 282                | 125            | 407      | 68%     |
| .2 - 9           | 74                 | 66             | 140      | 23      |
| 1 - 99           | 26                 | 17             | 43       | 7       |
| 10 - 299         | 3                  | 1              | 4        | <1      |
| 30 - 999         | 4                  | 1              | 5        | <1      |
| 1000 - 5000      | <u>1</u>           | <u>0</u>       | <u>1</u> | <1      |
| <b>Subtotals</b> | 390                | 210            | 600      |         |



| Month            | Number of Fires | Percent |
|------------------|-----------------|---------|
| November - March | 14              | 2%      |
| April            | 5               | <1      |
| May              | 4               | <1      |
| June             | 52              | 9       |
| July             | 175             | 29      |
| August           | 196             | 33      |
| September        | 92              | 15      |
| October          | <u>62</u>       | 10      |
| <b>Total</b>     | <b>600</b>      |         |

#### Summary of Fire History Table:

66% of the human-caused fires were within a thousand feet (300 meters) of a road.

The average number of fires per year is 16.

Most fires are less than half an acre (about 85%).

The most active fire month is August (196 fires), followed by July (175 fires).

The fewest fires occurred in 1993 (four), 1984 (six), and 1971 (seven).

The most fires occurred in 1981 (27), 1996 (26), and 1974 (24).

The largest fires were in 1994 (Edgar Canyon, 3,640 acres, Beaver Mountain, 617 acres, East Deweyville, 515 acres) and 1988 (Mountain Home, 612 acres).

The most acreage burned was in 1994 (5,316), 1974 (212), and 1982 (154).

#### Most fires occurring on Forest Service land were:

Between 6,000 and 8,000 feet.

On west aspects.

On the upper third of slopes.

In grass, sage-grass, brush, and mixed fir.

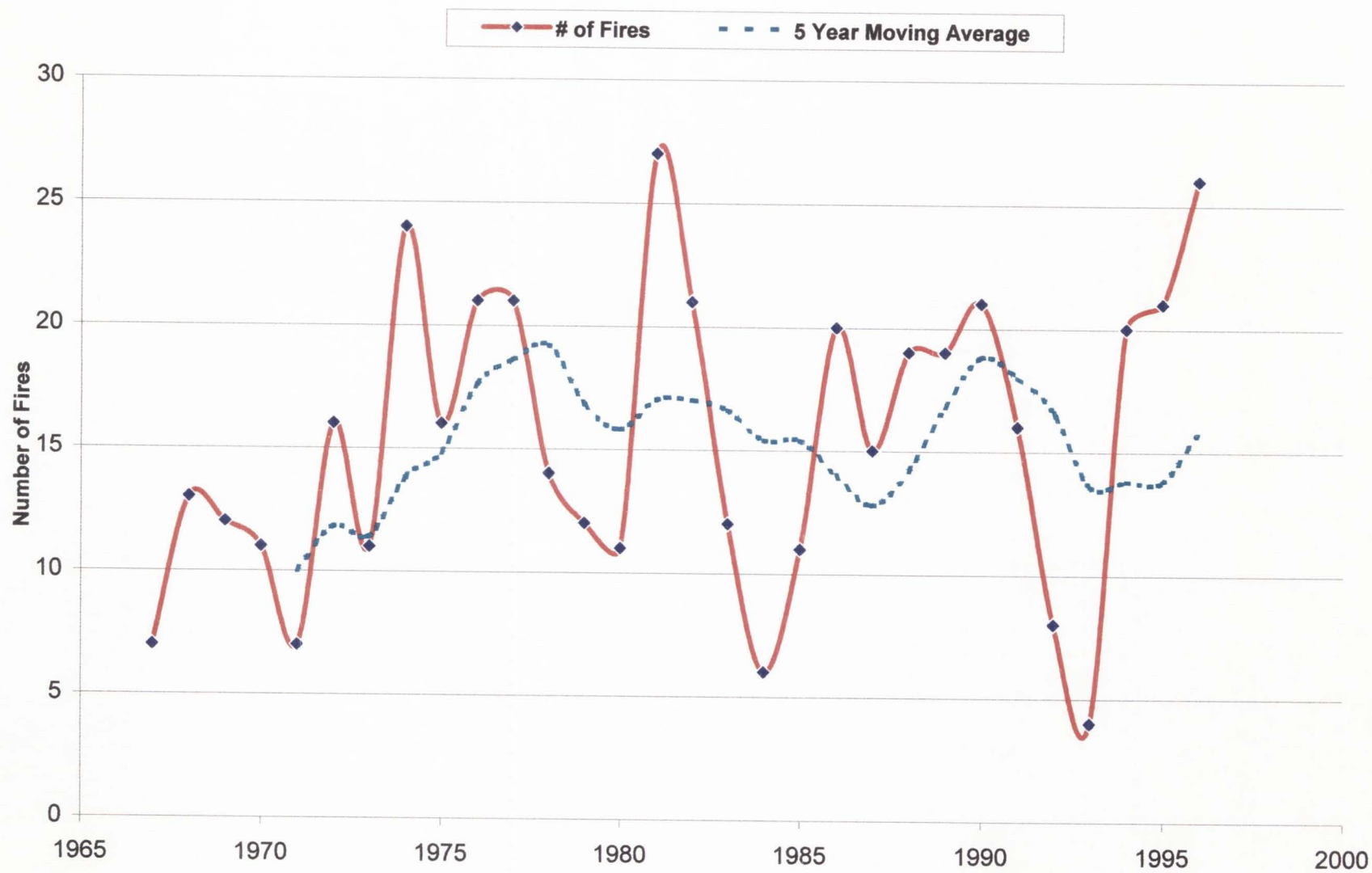


Figure 36. Number of fires per year on federal, state, county, and private lands (1968-1996).

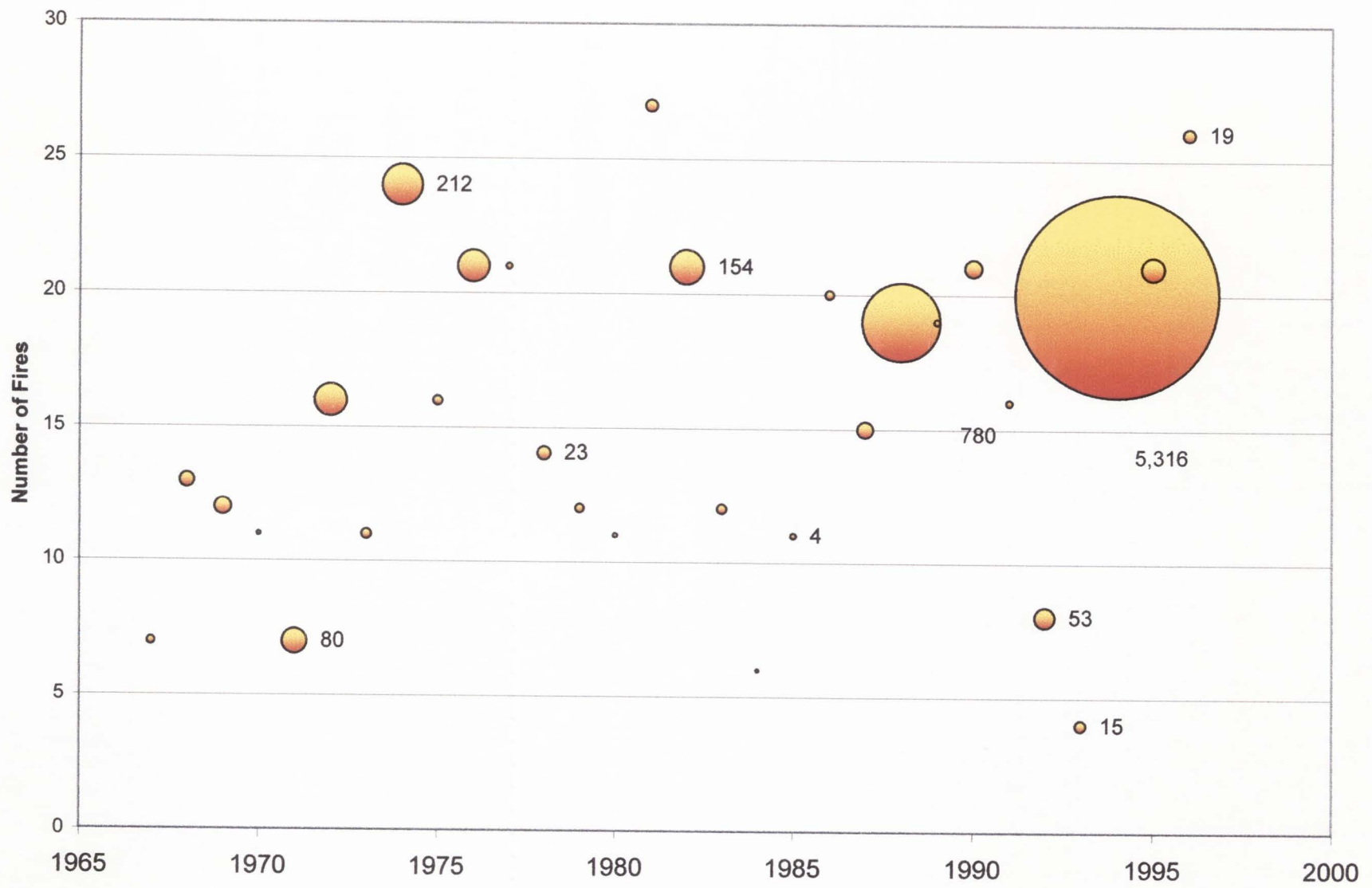


Figure 37. Number of acres burned per year on federal, state, county, and private lands (1968-1996).



## Appendix C

### Fire Reports

UNITED STATES DEPARTMENT OF AGRICULTURE  
FOREST SERVICEINDIVIDUAL FIRE REPORT  
(All classes of fires)Ranger fire No. 6

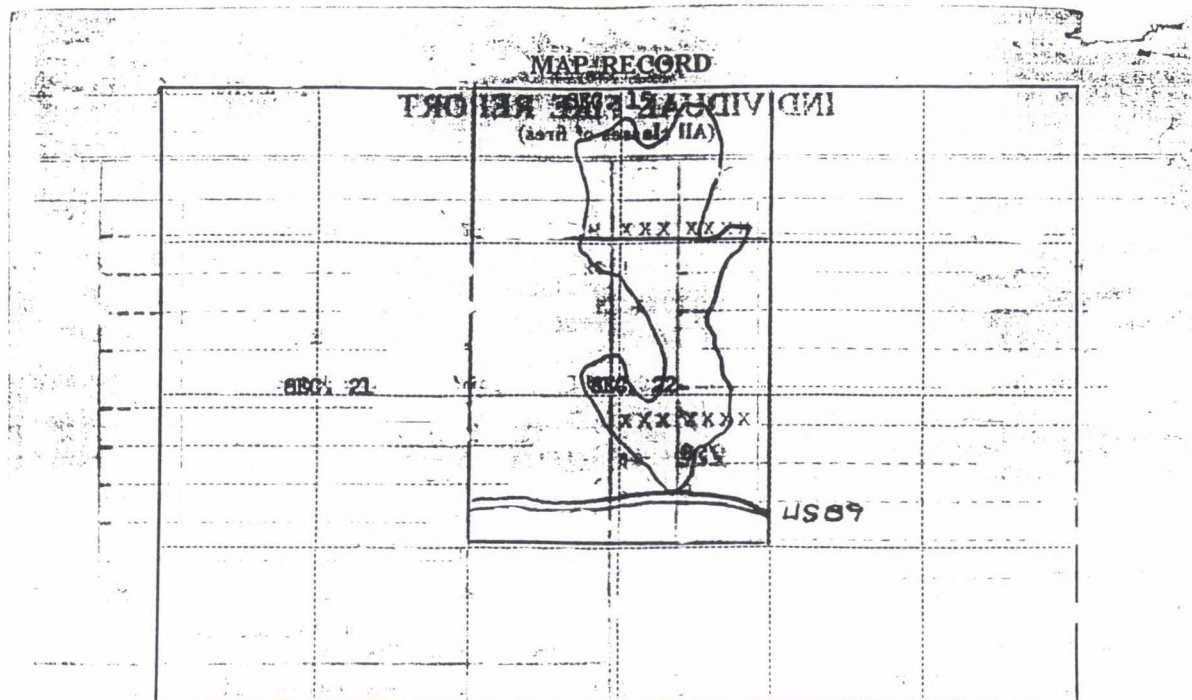
Region fire No. \_\_\_\_\_

| ITEM   | CODE NO.     | COL NO.     | ITEM   | CODE NO.                   | COL NO.      |
|--|--------------|-------------|--|----------------------------|--------------|
| 1. Name of fire <u>Malibu</u>  | X X X X      | X X X       | 34. Fuel type prevailing on burned area <u>HM</u>  |                            | 61-62        |
| 2. Ranger district <u>Logan</u>  |              | 1           | 35. Man hours to control (In tens) <u>0160</u>   |                            | 63-66        |
| 3. Forest <u>Cache</u>   |              | 2-3         | 36. Man hours to mop-up (In tens) <u>0160</u>  |                            | 67-70        |
| 4. Region <u>4</u>   |              | 4           | 37. Character of fire on arrival <u>Running</u>  |                            | 71           |
| 5. State <u>Utah</u>   |              | 5           | 38. Point of origin in feet from outer track of road or railroad (If over 99 feet, disregard) _____  |                            | 72-73        |
| 6. County <u>Cache</u>   | X X X X      | X X X       | 39. Slope <u>35%</u>   |                            | 74           |
| 7. Supervisor's fire number <u>058</u>   |              | 6-8         | 40. Exposure <u>S</u>  |                            | 75           |
| 8. Year discovered <u>8</u>  |              | 9           | 41. Elevation above sea <u>6500</u>  |                            | 76           |
| 9. Month discovered <u>0</u>   |              | 10          | 42. Method of travel <u>Foot</u>   |                            | 77           |
| 10. Day discovered <u>18</u>   |              | 11-12       | 43. Distance traveled—miles <u>01</u>  |                            | 78-79        |
| 11. FF cost class (\$ <u>6,000.00</u> )<br>(Approx. FF Cost)   |              | 13          | 44. Point origin in seen area from 0-1-2-3 L O. Stations<br>(Occupied <u>0</u> Unoccupied <u>0</u> ) |                            | 80           |
| 12. Size class ( <u>D</u> )  |              | 14          | 45. Line held by tankers or pumpers (Chains) <u>5</u>  |                            | 16-18        |
| 13. General cause <u>Smoker</u>  |              | 15          | 46. Line built by dozers (Chains) <u>None</u>  |                            | 19-21        |
| 14. Specific cause <u>Smoking</u>  |              | 16-17       | 47. Line built by plows (Chains) <u>None</u>   |                            | 22-24        |
| 15. Class of people <u>Hunter</u>  |              | 18-19       | 48. Line built by trenchers (Chains) <u>None</u>   |                            | 25-27        |
| 16. Fire started on <u>National Forest Land</u>  |              | 20          | 49. Line built by hand-tools (Chains) <u>165</u>   |                            | 28-31        |
| ELAPSED TIME   | DATE         | HOUR        | A. M.<br>P. M.   | ELAPSED TIME<br>Hours Min. |              |
| 17. Origin: <u>Known</u>   | <u>10/18</u> | <u>030</u>  |  | <u>000</u>                 |              |
| 18. Discovered (18-17)   | <u>10/18</u> | <u>0140</u> |  | <u>000</u>                 | <u>10</u>    |
| 19. Reported (19-18)   | <u>10/18</u> | <u>0150</u> |  | <u>0</u>                   | <u>10</u>    |
| 20. First attack (20-19)   | <u>10/18</u> | <u>0210</u> |  | <u>00</u>                  | <u>20</u>    |
| 21. First reinforcements (21-20)   | <u>10/18</u> | <u>0230</u> |  | <u>00</u>                  | <u>20</u>    |
| 22. Fire controlled (22-20)  | <u>10/18</u> | <u>1000</u> |  | <u>007</u>                 | <u>30</u>    |
| 23. Fire mopped up (23-22)   | <u>10/18</u> | <u>1800</u> |  | <u>008</u>                 | <u>00</u>    |
| 24. Fire out   | <u>10/20</u> | <u>1300</u> |  | <u>X X</u>                 | <u>X X X</u> |
| 25. Discovered by <u>Others</u> <u>Logan Canyon</u><br>(Class of discoverer) (Location)                          |              |             |  |                            |              |
| 26. Reported to <u>Forest Ranger</u> <u>Logan</u><br>(Title) (Location)  |              |             |  |                            |              |
| 27. Type of first attack <u>Pumpers</u>  |              |             |  |                            |              |
| 28. Number men first attack (Boss <u>City Fire Chief</u> )<br>(Title)  |              |             |  |                            |              |
| 29. Type reinforcement action <u>Pumper-Hand tools</u><br><u>organized suppression crews</u>                     |              |             |  |                            |              |
| 30. Number men first reinforcements <u>10</u>  |              |             |  |                            |              |
| 31. Danger rating class, or burning index <u>XX</u>  |              |             |  |                            |              |
| 32. Timber type—vicinity point of origin <u>11</u>   |              |             |  |                            |              |
| 33. Specific fuels in which fire spread <u>Grass</u><br>(Origin to attack)                                       |              |             |  |                            |              |
| 50. Area when discovered <u>50</u>   |              |             |  |                            |              |
| 51. Area when attacked <u>090</u>  |              |             |  |                            |              |
| 52. Area when controlled <u>145</u> (N. F. and other inside) (Outside)   |              |             |  |                            |              |
| 53. Perimeter in chains when controlled <u>00280</u>   |              |             |  |                            |              |
| 54. Perimeter increase in chains per hour discovery to attack <u>070</u>   |              |             |  |                            |              |
| 55. Wind velocity at time first attack (Direction) _____   |              |             |  |                            |              |
| 56. Wind velocity at time greatest run (Direction) _____   |              |             |  |                            |              |
| 57. Danger rating class or burning index at time of greatest run <u>XX</u>                                       |              |             |  |                            |              |
| 58. Maximum number of line workers <u>0210</u>   |              |             |  |                            |              |
| 59. Timber type _____ Acres burned _____   |              |             |  |                            |              |
| 60. Timber type _____ Acres burned _____   |              |             |  |                            |              |
| 61. Timber type _____ Acres burned _____   |              |             |  |                            |              |
| 62. Timber type _____ Acres burned _____   |              |             |  |                            |              |
| 63. Timber type _____ Acres burned _____   |              |             |  |                            |              |
| 64. Is this fire being reported by the State as its fire? <u>No</u>  |              |             |  |                            |              |
| 65. Is this fire being reported to State by any agency for Clarke-McNary record of fires in the State? <u>No</u> |              |             |  |                            |              |

## MANDATORY ITEMS:

1. Class A: 1-33; 64-65; and Map Record. 2. Class B: 1-36; 45-54; 64-65; Map Record; and 67-68. 3. Classes C-D-E: 1-36; 45-54; 64-65; Map Record; and 67-80.

Form FS 929  
(Revised 2-26-51)



Twp 12 N R 2 E Sec 15 & 22 Mer S.L. Scale 2 Inches = 1 mile.

### SUMMARY OF FIRE DAMAGE

For Class B fires—Lines 67 and 68 mandatory; lines 72 and 79 optional. For Class C and larger fires—all items mandatory.

| Objects of Damage                               | (1)<br>N. F. Lands | Col. No. | (2)<br>Other, Inside | Col. No. | (3)<br>Outside N. F.<br>Prot. by F. S. | Col. No. |
|---|--------------------|----------|----------------------|----------|--|----------|
| 67. Acres noncommercial forest burned           |                    | 16-20    |                      | 49-53    |  | 16-20    |
| 68. Acres commercial forest burned              |                    | 21-25    |                      | 54-58    |  | 21-25    |
| 69. MBM timber destroyed (Convert cords to MBM) |                    | 26-29    |                      | 59-62    |  | 26-29    |
| 70. Acres young growth destroyed                |                    | 30-33    |                      | 63-66    |  | 30-33    |
| 71. Other timber values (Dollars)               | None               | X X X    |                      | X X X    |  | X X X    |
| 72. Total timber values (Dollars)               |                    | 34-38    |                      | 67-71    |  | 34-38    |
| 73. Watershed damage (Dollars)                  | 0050.00            | 39-43    |                      | 72-75    |  | 39-43    |
| 74. Recreation damage (Dollars)                 | \$200.00           | X X X    |                      | X X X    |  | X X X    |
| 75. Wildlife damage (Dollars)                   | \$500.00           | X X X    |                      | X X X    |  | X X X    |
| 76. Improvements damage (Dollars)               | None               | X X X    |                      | X X X    |  | X X X    |
| 77. Forage damage (Dollars)                     | None               | X X X    |                      | X X X    |  | X X X    |
| 78. Other nontimber values damage (Dollars)     | None               | X X X    |                      | X X X    |  | X X X    |
| 79. Total nontimber values damage (Dollars)     | 0120.00            | 44-48    |                      | 76-80    |  | 44-48    |
| 80. GRAND TOTAL damage (Dollars)                | \$1200.00          | X X X    |                      | X X X    |  | X X X    |

REMARKS: Law enforcement investigation revealed probable cause as burning material thrown from car on highway. Hunter traffic was very heavy & no evidence found as to responsible party.

(a) Date report written 29 October 1958 (c) Examined and approved PPH  
(Day) (Month) (Year) (Initials (Supervisor or acting))

(b) By PPH  
(Initials (Reporter or acting))



Form FC-1, Rev. 2-67

STATE OF UTAH  
DEPARTMENT OF FORESTRY & FIRE CONTROL

CM-2 ☒  
Non CM-2 ☐

Fire Report

|  |                  |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
|--|------------------|-----------------|------|--------------------|---------------|--------------|--------------------|--------------|--------------|----------------------|--------------|-------------|--|--------------|-------------|-----------------------|----------|-------------|----------------------------------|----------|-------------|----------------|--|-------------|------------------------|--|-----------------|--|-------------------|-------|-----------------------|-------|------------------------|-----------|------------------|-------|-------|-----------|-----------|-------|---------------------|-------|--------|----------------|-----------|---------------|------------|-------|----------|-------|---------------|-------|-------------------|-------|-------|------------------|
| <p>1. Name of Fire <u>Del Adonis Range</u></p> <p>3. Location <u>Mantua</u></p> <p>a. County <u>Box Elder</u></p> <p>b. Sec <u>4</u> T <u>9</u> N&amp;R <u>1</u> <u>4W</u></p> <p>4. CAUSE OF FIRE:</p> <p>a. L CF S DB I <u>Mach</u> Misc _____</p> <p>b. Cause by responsibility <u>Hunter</u></p> <p>6. SIZE CLASS: A B <u>C</u> D E F G - FA</p> <p>7. DETECTION:</p> <p>a. By: <u>State Road Boss</u></p> <p>b. Reported to: <u>Dispatcher then Thomas Hauer</u></p> <p>c. How reported: <u>Radio</u></p> <p>9. SUPPRESSION:</p> <table border="0" style="width: 100%;"> <tr> <td></td> <td style="text-align: center;">Hours</td> <td style="text-align: center;">Cost</td> </tr> <tr> <td>No. Men 1st Attack</td> <td style="text-align: center;"><u>8-4-32</u></td> <td style="text-align: center;"><u>60.40</u></td> </tr> <tr> <td>No. Reinforcements</td> <td style="text-align: center;"><u>4-2-8</u></td> <td style="text-align: center;"><u>14.00</u></td> </tr> <tr> <td>Other Equipment used</td> <td style="text-align: center;"><u>1-3-3</u></td> <td style="text-align: center;"><u>5.25</u></td> </tr> <tr> <td></td> <td style="text-align: center;"><u>2-1-2</u></td> <td style="text-align: center;"><u>3.50</u></td> </tr> <tr> <td><u>use of 2 pumps</u></td> <td style="text-align: center;"><u>2</u></td> <td style="text-align: center;"><u>4.00</u></td> </tr> <tr> <td><u>Stand by line for 2 pumps</u></td> <td style="text-align: center;"><u>8</u></td> <td style="text-align: center;"><u>8.00</u></td> </tr> <tr> <td><u>Mileage</u></td> <td></td> <td style="text-align: center;"><u>8.40</u></td> </tr> <tr> <td>Total Suppression Cost</td> <td></td> <td style="text-align: center;"><u>\$103.55</u></td> </tr> </table> <p>10. LAND OWNERSHIP:</p> <p>a. Fire started on <u>Del Adonis</u></p> <p>b. Burned on: OWNERSHIP ACRES</p> <p><u>Same</u> <u>40</u></p> <p>_____</p> <p>_____</p> <p>_____</p> <p style="text-align: right;">TOTAL <u>40</u></p> |                  | Hours           | Cost | No. Men 1st Attack | <u>8-4-32</u> | <u>60.40</u> | No. Reinforcements | <u>4-2-8</u> | <u>14.00</u> | Other Equipment used | <u>1-3-3</u> | <u>5.25</u> |  | <u>2-1-2</u> | <u>3.50</u> | <u>use of 2 pumps</u> | <u>2</u> | <u>4.00</u> | <u>Stand by line for 2 pumps</u> | <u>8</u> | <u>8.00</u> | <u>Mileage</u> |  | <u>8.40</u> | Total Suppression Cost |  | <u>\$103.55</u> | <p>2. Date of Fire _____ Date _____</p> <p>a. Start <u>Sept 18</u> <u>1968</u></p> <p>b. Declared out <u>Sept 19</u> <u>1968</u></p> <p>5. BURNING CONDITIONS:</p> <p>a. Fuel type involved in _____</p> <p>Start <u>Grass</u> Spread <u>Brush Grass</u></p> <p>b. Wind: Direction <u>West</u> mph <u>3 to 10</u></p> <p>c. Topograph: Elevation <u>5680</u></p> <p>Slope <u>fairly steep</u> Exposure <u>West</u></p> <p>d. Rate of Spread <u>fast to slow</u></p> <p>8. DAMAGE:</p> <p>a. In Acres: _____</p> <table border="0" style="width: 100%;"> <tr> <td>Commercial Forest</td> <td>_____</td> </tr> <tr> <td>Non-Commercial Forest</td> <td>_____</td> </tr> <tr> <td>Non-Forested Watershed</td> <td style="text-align: center;"><u>40</u></td> </tr> <tr> <td>Non-Forest (RFD)</td> <td>_____</td> </tr> <tr> <td style="text-align: right;">TOTAL</td> <td style="text-align: center;"><u>40</u></td> </tr> </table> <p>b. In Dollar Value: _____</p> <table border="0" style="width: 100%;"> <tr> <td>Sawtimber</td> <td>_____</td> </tr> <tr> <td>Other wood products</td> <td>_____</td> </tr> <tr> <td>Forage</td> <td style="text-align: center;"><u>2900.00</u></td> </tr> <tr> <td>Watershed</td> <td style="text-align: center;"><u>200.00</u></td> </tr> <tr> <td>Recreation</td> <td>_____</td> </tr> <tr> <td>Wildlife</td> <td>_____</td> </tr> <tr> <td>Real Property</td> <td>_____</td> </tr> <tr> <td>Personal Property</td> <td>_____</td> </tr> <tr> <td style="text-align: right;">TOTAL</td> <td style="text-align: center;"><u>\$4200.00</u></td> </tr> </table> <p>11. LAW ENFORCEMENT ACTION</p> <p>Prosecuted _____ Convicted _____</p> <p>Settled for Costs _____</p> | Commercial Forest | _____ | Non-Commercial Forest | _____ | Non-Forested Watershed | <u>40</u> | Non-Forest (RFD) | _____ | TOTAL | <u>40</u> | Sawtimber | _____ | Other wood products | _____ | Forage | <u>2900.00</u> | Watershed | <u>200.00</u> | Recreation | _____ | Wildlife | _____ | Real Property | _____ | Personal Property | _____ | TOTAL | <u>\$4200.00</u> |
|  | Hours            | Cost            |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| No. Men 1st Attack   | <u>8-4-32</u>    | <u>60.40</u>    |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| No. Reinforcements   | <u>4-2-8</u>     | <u>14.00</u>    |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Other Equipment used   | <u>1-3-3</u>     | <u>5.25</u>     |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
|  | <u>2-1-2</u>     | <u>3.50</u>     |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| <u>use of 2 pumps</u>  | <u>2</u>         | <u>4.00</u>     |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| <u>Stand by line for 2 pumps</u>   | <u>8</u>         | <u>8.00</u>     |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| <u>Mileage</u>   |                  | <u>8.40</u>     |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Total Suppression Cost   |                  | <u>\$103.55</u> |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Commercial Forest  | _____            |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Non-Commercial Forest  | _____            |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Non-Forested Watershed   | <u>40</u>        |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Non-Forest (RFD)   | _____            |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| TOTAL  | <u>40</u>        |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Sawtimber  | _____            |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Other wood products  | _____            |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Forage   | <u>2900.00</u>   |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Watershed  | <u>200.00</u>    |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Recreation   | _____            |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Wildlife   | _____            |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Real Property  | _____            |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| Personal Property  | _____            |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |
| TOTAL  | <u>\$4200.00</u> |                 |      |                    |               |              |                    |              |              |                      |              |             |  |              |             |                       |          |             |                                  |          |             |                |  |             |                        |  |                 |  |                   |       |                       |       |                        |           |                  |       |       |           |           |       |                     |       |        |                |           |               |            |       |          |       |               |       |                   |       |       |                  |

12. REMARKS: The State Road Boss said there had been a Green pick-up on the road at the morning. They heard the shooting but ~~person~~ thought nothing of it. See them come down when this unit in to get search when they came back out they saw the ~~person~~ there for disarming and had it all out but not any the ~~person~~ came up and then lost ~~person~~ on callen is

Report Prepared by Thomas Hauer

District Fire # 19 Title District Fire Warden

State Fire # \_\_\_\_\_ Date Sept 30 1968

White - State Office  
Yellow - Area Office  
Pink - District Firewarden

| USDA - FOREST SERVICE  |                                       |   |   | FIRE NAME   |   | RANGER FIRE NO.   |  |
|--|---------------------------------------|---|---|---|---|-------------------|--|
| INDIVIDUAL FIRE REPORT   |                                       |   |   | Precipice Canyon  |   | 11                |  |
|  |                                       |   |   | MANDATORY ITEMS:  |   | REGION FIRE NO.   |  |
|  |                                       |   |   | CLASS A 1-33  |   |                   |  |
|  |                                       |   |   | CLASS B 1-34  |   | CLASS C to G 1-44 |  |
| 1. State (2-3)<br>Utah   | 2. County (4-5)<br>Box Elder          | 3. Forest (6-7)<br>Wasatch  | 4. District (8-9)<br>Logan              | 5. Supervisor (10-11)<br>No. 020  |   |                   |  |
| 6. Fire started on (12)<br>National Forest 1                                 | 7. Month (13)<br>August 8             | 8. Day (14-15)<br>28 28   | 9. Year (16-17)<br>82 2                 | 10. Watershed No. (18-23)<br>16010202   | 11. Size Class (24)<br>.1 Acre A  |                   |  |
| 12. Statistical Cause (25)<br>Lightning 1                                    | 13. General Cause (26)<br>Lightning 0 | 14. Specific Cause (27-28)<br>Lightning 01  | 15. Class of people (29)<br>Lightning 0 |   |   |                   |  |
| 16. DATE<br>Mo. Day  |                                       | 17. HOUR  | 18. ELAPSED TIME<br>Hours Min           | 19. Slope (30)<br>70 - 79   | 20. Aspect (31)<br>North  |                   |  |
| 14. Origin<br>8/28   |                                       | 15. 1100  | 16. 11                                  | 21. Elevation (32)<br>7501 - 8500   | 22. Cover type - vicinity of origin (33-34)<br>Douglas Fir - All other  |                   |  |
| 15. Discovered (Item 15 minus 14)<br>8/28                                    |                                       | 16. 1115  | 17. 00 15                               | 23. Fuel type - vicinity of origin (35-36)<br>L - M   | 24. Cost Class (37)<br>Inside planned area  |                   |  |
| 16. First attack (Item 16 minus 15)<br>None                                  |                                       | 17. 00  | 18. 00                                  | 25. Location (38)<br>2  | 26. Location description (39-40)<br>a. Township 10N 010W<br>b. Range 2 W 002W<br>c. Section 2 00<br>d. Meridian SLC |                   |  |
| 17. First Reinforcement (Item 17 minus 16)<br>None                           |                                       | 18. 0   | 19. 00                                  | 27. Alternate description of lands not covered by GLO survey (41-42)<br>e. Latitude 41N<br>f. Longitude 112W  |   |                   |  |
| 18. Fire Controlled (Item 18 minus 16)<br>NA                                 |                                       | 19. 000   | 20. 00                                  | 28. Acres burned (43-44)<br>a. Noncommercial forest (11-16)<br>b. Commercial forest (17-21)<br>(1) Natural<br>(2) Plantation<br>c. Nonforest (22-27)<br>35. Volume of timber destroyed (MEM) (54-59)          |   |                   |  |
| 19. Fire Out<br>8/31   |                                       | 20. 1700  | 21. 00                                  | 36. Total area when controlled (60-70)<br>37. Fuel type prevailing on burned area (71-76)<br>38. Topography (vicinity of origin) (77)<br>39. Highest Fire Danger (78-79)<br>40. Critical Weather Feature (80) |   |                   |  |
| 20. Discovered by (Class) Location On Site<br>Cooperator (Box Elder Sheriff) |                                       | 21. First Attack by (Kind) (Amount)<br>None 00  |   | 22. First Reinforcements (Kind) (Amount)<br>None 00   |   |                   |  |
| 23. Maximum No. Personnel<br>10  |                                       | 24. Value Class at Origin<br>8  |   | 25. Fire danger<br>B1 0   |   |                   |  |
| 26. Special Weather feature<br>S.O. please provide                           |                                       | 27. 00  |   | 28. 00  |   |                   |  |
| 29. Remarks (Continue on reverse if required)                                |                                       | This fire was in an inaccessible cliff and crag area. It was burning in several fir trees with practically no understory or fuel for several hundred feet. No chance of spreading. The fire area was fogged in until approximately 1700 hours Saturday, August 28, 1982. Sunday, August 29, 1982, a crew was made available and the fire was surveyed by helicopter. It was considered unsafe to place workers on. It was monitored until considered dead out on 8/31/82 at 1700. |   |   |   |                   |  |
| Submitted (Signature)<br><i>[Signature]</i><br>(Acting) Chief Ranger         |                                       | Date<br>9/2/82  |   | Approved (Signature)<br><i>[Signature]</i><br>(Acting) Forest Supervisor  |   | Date<br>9/7/82    |  |

Previous Edition Obsolete

FS-5100-29 (1/86)

USDA - Forest Service

Fire Name Herd Hollow

INDIVIDUAL FIRE REPORT

Local Fire Number 5 (P-48883)

(Ref. FSH 5109.14)

Location T11N, R3E Sec. 9IDENTIFICATION

|   |             |
|---|-------------|
| 1. Region/Forest/District ID and SO Fire Number   | 04/19/07/08 |
| 2. Protecting Agency at Origin                    | USF         |
| 3. Ownership at Origin/State at Origin            | 2/UT        |
| 4. Fire Management Analysis Zone                  | 12          |
| 5. Adjoining Forest Report Number (if applicable) | * / / /     |

OCCURRENCE

|  |                  |
|--|------------------|
| 6. Point of Origin lat= 41 44 30                       | long = 111 37 00 |
| 7. Time of Origin                                      | 08/06/95/1800    |
| 8. Time of Discovery                                   | 08/07/95/1415    |
| 9. Detection Method                                    | 6                |
| 10. Statistical Cause                                  | 4                |
| 11. Unplanned Ignition Designated as a Prescribed Fire | *                |

ACTION

|  |                 |
|--|-----------------|
| 12. Initial Suppression Strategy             | 3               |
| 13. Escaped Fire                             | N               |
| 14. Time of Initial Action                   | 08/07/95/1445   |
| 15. Time Final Suppression Strategy Attained | 08/08/95/1600   |
| 16. Time Fire Out                            | 08/11/95/1800   |
| 17. Forces Used                              | E6/F/02 M1/F/05 |
| Up to Time of                                | / / /           |
| Attainment of                                | * / /           |
| Initial Strategy                             | * / /           |
| or Escape                                    | * / /           |

DESCRIPTION

|                                       |                       |
|---------------------------------------|-----------------------|
| 18. FFF Cost (\$ hundreds)            | 10                    |
| 19. FMAZ NVC per Acre (whole \$)      | 1                     |
| 20. NFS Acres (Reporting Forest Only) | 1                     |
| 21. Other Acres Inside                | *                     |
| 22. Other Acres Outside               | *                     |
|                                       | Total Acres= <u>1</u> |
| 23. Fire Intensity Level              | 6                     |
| 24. Representative Weather Station    | 420201                |
| 25. NFDRS Fuel Model/Cover Type       | C/20                  |
| 26. Aspect                            | 7                     |
| 27. Elevation (feet hundreds)         | 65                    |

OPTIONS

|                  |      |     |     |
|------------------|------|-----|-----|
| 28. Special Code | WS/2 | * / | * / |
|                  | * /  | * / | * / |
|                  | * /  | * / | * / |
|                  | * /  | * / | * / |

REMARKSSubmitted/s/Gerald A. Brunner/d/ 8/09/95 Approved/s/\* /d/\*



## Utah Forestry, Fire and State Lands

## Fire Report

|              |               |  |                    |      |
|--------------|---------------|--|--------------------|------|
| Prepared by: | KELLY PITCHER |  | State Fire Number  |      |
| Title:       | CACHE FW      |  | County Fire Number | 0096 |

|               |            |               |                 |          |                 |  |
|---------------|------------|---------------|-----------------|----------|-----------------|--|
| Name of fire: | HELICOPTER | Fire Started: | Time & Date     | Fire Out | Time & Date     | <input type="checkbox"/> Under Investigation |
|               |            |               | 10:33 22 Mar 96 |          | 13:30 22 Mar 96 |  |

|        |                  |   |      |   |   |     |   |  |         |                    |
|--------|------------------|---|------|---|---|-----|---|--|---------|--------------------|
| County | Location of Fire | T | 10.0 | <input checked="" type="radio"/> N<br><input type="radio"/> S | R | 2.0 | <input checked="" type="radio"/> E<br><input type="radio"/> W | <input checked="" type="radio"/> SLBM<br><input type="radio"/> USM | Section | Initial Attack by: |
| Cache  |                  |   |      |   |   |     |   |  | 4       | County             |

|            |               |                |         |          |              |
|------------|---------------|----------------|---------|----------|--------------|
| Fire Cause | General Cause | Specific Cause | Person  | Activity | Type of Fire |
|            | Equipment     | Electrical     | Visitor | Work     | Interface    |

|                           |                     |      |           |      |                 |  |                        |      |
|---------------------------|---------------------|------|-----------|------|-----------------|--|------------------------|------|
| Acres Burned by Ownership | Private             | 5.00 | BLM       | 0.00 | Size Class<br>B | Acres Damaged by type<br>(DO NOT REPORT FEDERAL ACRES) | Commercial Forest      | 0.00 |
|                           | State               | 0.00 | USFS      | 0.00 |                 |  | Non-Commercial Forest  | 5.00 |
|                           | Other               | 0.00 | Other Fed | 0.00 |                 |  | Non-Forested Watershed | 0.00 |
|                           | Total Acres Damaged |      | 5.00      |      |                 |  |                        |      |

| SUPPRESSION COSTS                             |              |             |             |                |                |            |                 |   |     |
|---|--------------|-------------|-------------|----------------|----------------|------------|-----------------|---|-----|
| <input type="checkbox"/> Cost Share Agreement |              |             | Personnel   |                | Equipment      |            |                 |   |     |
|   |              |             | Agency      | Cost/Hr.       | Total Hrs.     | Cost       | Cost/Hr.        |   |     |
| <input type="checkbox"/> Costs Recoverable    |              |             | COUNTY      | 7              | 3              | 21         | 26              | 3 | 78  |
|   |              |             | FIRE DEPT   | 6              | 3              | 18         | 26              | 6 | 156 |
| Aircraft Cost                                 | Supply Costs | Other Costs | FIRE DEPT   | 0              | 0              | 0          | 45              | 6 | 270 |
|   |              |             |             | 0              | 0              | 0          | 0               | 0 | 0   |
|   |              |             |             | 0              | 0              | 0          | 0               | 0 | 0   |
|   |              |             |             | 0              | 0              | 0          | 0               | 0 | 0   |
|   |              |             |             | 0              | 0              | 0          | 0               | 0 | 0   |
| 0   | 45           | 0           |             | 0              | 0              | 0          | 0               | 0 | 0   |
| 0   | 0            | 0           | 99          | 444            | 0              | 0          | 588             |   |     |
| STATE COST                                    | BLM COST     | USFS COST   | COUNTY COST | FIRE DEPT COST | OTHER FED COST | OTHER COST | TOTAL FIRE COST |   |     |

| RESOURCE DAMAGE   |    |                   |       |
|-------------------|----|-------------------|-------|
| Sawtimber         | 0  | Recreation        | 0     |
| Other Wood Prdcts | 0  | Real Property     | 1,000 |
| Forage            | 0  | Wildlife          | 0     |
| Watershed         | 11 | Personal Property | 0     |

| RESOURCE VALUE SAVED |    |                   |        |
|----------------------|----|-------------------|--------|
| Sawtimber            | 0  | Recreation        | 0      |
| Other WoodPrdcts     | 0  | Real Property     | 15,000 |
| Forage               | 0  | Wildlife          | 0      |
| Watershed            | 90 | Personal Property | 85,000 |

## Additional Information

FIRE WAS STARTED WHEN A HELICOPTER WORKING A LOGGING OPERATION ALLOWED A LOG TO COME IN CONTACT WITH A POWER LINE, KNOCKING IT TO THE GROUND AND STRTING THIS FIRE. THE FIRE WAS NEAR SEVERAL SUMMER HOMES AND UTILITY AREAS.

## Appendix D

Sample Data Points from ARC/GRID "Sample" Command and Their  
Descriptive Information for the Wellsville Human Data Set

Appendix D. Sample data points from ARC/GRID "sample" command and their descriptive information for the Wellsville human data set.

| Obs. Num. | Area  | X      | Y       | Slope | Aspect | Elevation | Precip. | Temp. |
|-----------|-------|--------|---------|-------|--------|-----------|---------|-------|
| 254       | wells | 412076 | 4627090 | 5     | 315    | 1453      | 18      | 47    |
| 263       | wells | 410396 | 4626400 | 5     | 315    | 1395      | 18      | 47    |
| 269       | wells | 409496 | 4625890 | 7     | 315    | 1409      | 17      | 47    |
| 275       | wells | 410096 | 4625350 | 6     | 315    | 1439      | 18      | 47    |
| 283       | wells | 410876 | 4624930 | 8     | 333    | 1498      | 19      | 46    |
| 298       | wells | 414806 | 4624060 | 7     | 108    | 1527      | 20      | 46    |
| 301       | wells | 415106 | 4624000 | 8     | 360    | 1525      | 20      | 46    |
| 309       | wells | 411566 | 4623340 | 27    | 63     | 1614      | 20      | 45    |
| 310       | wells | 415616 | 4623310 | 13    | 74     | 1500      | 21      | 46    |
| 315       | wells | 413336 | 4622860 | 20    | 296    | 1658      | 21      | 44    |
| 337       | wells | 409616 | 4621090 | 20    | 281    | 1457      | 20      | 44    |
| 340       | wells | 410306 | 4620700 | 58    | 292    | 1598      | 22      | 43    |
| 350       | wells | 410456 | 4620220 | 56    | 304    | 1831      | 22      | 42    |
| 351       | wells | 412376 | 4620160 | 41    | 71     | 1923      | 24      | 40    |
| 356       | wells | 410666 | 4619620 | 72    | 158    | 1629      | 23      | 42    |
| 361       | wells | 413096 | 4619410 | 30    | 71     | 1948      | 25      | 39    |
| 363       | wells | 413726 | 4619230 | 28    | 297    | 1977      | 25      | 39    |
| 369       | wells | 415196 | 4618690 | 18    | 109    | 1684      | 24      | 40    |
| 370       | wells | 415436 | 4618630 | 10    | 98     | 1642      | 24      | 40    |
| 373       | wells | 417986 | 4618390 | 5     | 45     | 1410      | 22      | 43    |
| 377       | wells | 416426 | 4617670 | 25    | 45     | 1612      | 24      | 40    |
| 379       | wells | 418136 | 4617460 | 8     | 90     | 1423      | 23      | 41    |
| 381       | wells | 410336 | 4617370 | 45    | 249    | 1517      | 23      | 41    |
| 383       | wells | 415256 | 4617310 | 50    | 11     | 1849      | 26      | 37    |
| 384       | wells | 418916 | 4617070 | 3     | 90     | 1365      | 22      | 43    |
| .         | .     | .      | .       | .     | .      | .         | .       | .     |
| .         | .     | .      | .       | .     | .      | .         | .       | .     |
| .         | .     | .      | .       | .     | .      | .         | .       | .     |



| Trails     | Roads      | Lightning | Rand. Num.  | Veg. | Date | Owner. | Solar Rad.    | Fire |
|------------|------------|-----------|-------------|------|------|--------|---------------|------|
| 4583.31291 | 144.47499  | 3         | 0.083577583 | 2    | 0    | 8      | 2.6115720E+07 | 0    |
| 4380.57116 | 210.06098  | 3         | 0.291497265 | 2    | 0    | 8      | 2.6115720E+07 | 0    |
| 4460.8721  | 17.67448   | 3         | 0.971812279 | 2    | 0    | 8      | 2.5947310E+07 | 0    |
| 3661.75128 | 237.17056  | 4         | 0.260192924 | 2    | 0    | 8      | 2.5539560E+07 | 0    |
| 2864.62452 | 578.55442  | 5         | 0.845430723 | 18   | 0    | 8      | 2.5645870E+07 | 0    |
| 2813.28285 | 199.15758  | 4         | 0.529995988 | 2    | 0    | 8      | 2.5645870E+07 | 0    |
| 3039.24236 | 500.36382  | 4         | 0.367139184 | 2    | 0    | 8      | 2.4050090E+07 | 0    |
| 1181.24533 | 790.27948  | 5         | 0.046040303 | 18   | 0    | 8      | 2.4050090E+07 | 0    |
| 3262.25742 | 298.84685  | 4         | 0.583319579 | 2    | 0    | 8      | 2.3792980E+07 | 0    |
| 947.96149  | 695.21886  | 6         | 0.944152816 | 19   | 0    | 8      | 2.3792980E+07 | 0    |
| 2121.76534 | 205.0349   | 4         | 0.253645287 | 18   | 0    | 8      | 2.6254450E+07 | 0    |
| 1358.11106 | 238.04345  | 4         | 0.687062581 | 19   | 0    | 8      | 2.5498450E+07 | 0    |
| 1203.89589 | 385.53527  | 4         | 0.484496671 | 10   | 0    | 8      | 2.3571680E+07 | 0    |
| 329.14266  | 689.75214  | 5         | 0.838224455 | 16   | 0    | 8      | 2.4618190E+07 | 0    |
| 1273.42906 | 467.58583  | 3         | 0.332774848 | 18   | 0    | 13     | 2.6404290E+07 | 0    |
| 342.38084  | 1024.82657 | 3         | 0.160284365 | 16   | 0    | 13     | 2.4882540E+07 | 0    |
| 987.91268  | 501.91176  | 3         | 0.452161344 | 16   | 0    | 13     | 2.4403650E+07 | 0    |
| 508.96781  | 37.0171    | 2         | 0.852269688 | 16   | 0    | 8      | 2.6828110E+07 | 0    |
| 382.22864  | 107.63756  | 2         | 0.446334527 | 2    | 0    | 8      | 2.6469480E+07 | 0    |
| 2501.24736 | 147.8576   | 2         | 0.075055948 | 2    | 0    | 8      | 2.6843560E+07 | 0    |
| 1100.54116 | 302.26534  | 2         | 0.993293456 | 2    | 0    | 8      | 2.4842250E+07 | 0    |
| 2761.66711 | 84.26138   | 2         | 0.909408777 | 2    | 0    | 8      | 2.6681540E+07 | 0    |
| 2826.34381 | 418.93781  | 2         | 0.301710819 | 19   | 0    | 13     | 2.5991060E+07 | 0    |
| 592.7468   | 965.49739  | 3         | 0.147862947 | 16   | 0    | 8      | 1.9320890E+07 | 0    |
| 3623.63477 | 270.17298  | 2         | 0.530657067 | 2    | 0    | 8      | 2.6582680E+07 | 0    |
| 2908.84276 | 400.82034  | 3         | 0.233607058 | 15   | 0    | 13     | 1.9913070E+07 | 0    |
| 3760.72657 | 158.15288  | 2         | 0.678954619 | 2    | 0    | 8      | 2.6750910E+07 | 0    |
| 2083.52823 | 686.74278  | 4         | 0.690075657 | 16   | 0    | 8      | 2.5143850E+07 | 0    |
| 2423.52797 | 199.26365  | 3         | 0.769887217 | 2    | 0    | 8      | 2.4981220E+07 | 0    |
| 1940.17131 | 115.88205  | 4         | 0.746466999 | 16   | 0    | 8      | 2.5970390E+07 | 0    |
| .          | .          | .         | .           | .    | .    | .      | .             | .    |
| .          | .          | .         | .           | .    | .    | .      | .             | .    |
| .          | .          | .         | .           | .    | .    | .      | .             | .    |

## Appendix E

Multiple Logistic Regression Output Used to Develop the Wellsville  
Human Predicted Fire Probability Grid

Appendix E. Multiple logistic regression output used to develop the Wellsville human predicted fire probability grid.

| X        | Y       | P(Fire) |
|----------|---------|---------|
| 409170   | 4618690 | 0.397   |
| 409170   | 4619040 | 0.3832  |
| 409170   | 4619390 | 0.3952  |
| 409170   | 4619740 | 0.3916  |
| 409170   | 4620090 | 0.3745  |
| 409335.2 | 4617990 | 0.3851  |
| 409335.2 | 4618340 | 0.3681  |
| 409335.2 | 4618690 | 0.3611  |
| 409335.2 | 4619040 | 0.38    |
| 409335.2 | 4619390 | 0.397   |
| 409335.2 | 4619740 | 0.3944  |
| 409335.2 | 4620090 | 0.3959  |
| 409335.2 | 4620440 | 0.3873  |
| 409335.2 | 4620790 | 0.3702  |
| 409335.2 | 4621140 | 0.353   |
| 409335.2 | 4621490 | 0.3358  |
| 409335.2 | 4621840 | 0.3187  |
| 409335.2 | 4622190 | 0.3015  |
| 409500.3 | 4616940 | 0.3903  |
| 409500.3 | 4617290 | 0.3732  |
| 409500.3 | 4617640 | 0.3561  |
| 409500.3 | 4617990 | 0.3456  |
| 409500.3 | 4618340 | 0.3389  |
| 409500.3 | 4618690 | 0.3542  |
| 409500.3 | 4619040 | 0.3818  |
| 409500.3 | 4619390 | 0.3988  |
| 409500.3 | 4619740 | 0.3927  |
| 409500.3 | 4620090 | 0.3937  |
| 409500.3 | 4620440 | 0.3952  |
| 409500.3 | 4620790 | 0.3966  |
| 409500.3 | 4621140 | 0.383   |
| 409500.3 | 4621490 | 0.3658  |
| 409500.3 | 4621840 | 0.3487  |
| 409500.3 | 4622190 | 0.3315  |

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